Study of recycled tyre rubber in asphalt concrete mixtures

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ABSTRACT: The study investigates the effects of the addition of crumb tyre rubber in asphalt concrete mixtures. The reaction of crumb rubber in the asphalt binder is observed through a microscope. The process of incorporation of rubber is similar to the aggregate-rubber process (dry), but seeking the asphalt-rubber process (wet). The study optimises the asphalt binder and rubber contents with the aid of the Marshall method. The mixture performance is evaluated with the indirect tensile strength, resilient modulus and fatigue tests on Marshall samples. The pavement design simulation with the experimental mixture shows advantages compared to the conventional mixture.

RÉSUMÉ: L'étude porte sur l'effect de l'addition de la poudrette de caoutchouc dans un enrobé bitumineux. La reaction du caoutchouc du pneu dans le liant bitumineux est observé au microscope. Le procédé d'incorporation du caoutchouc est pareill au procédé dit sec, toutefois, en envisagent le procédé dit humide. L'étude optimise les teneurs en liant et en caoutchouc du pneu avec l'aide de la méthode Marshall. Le comportment du mélange est évalué à l'aide de l'essai de la traction indirecte, du module résilient et de la fatigue avec des éprouvettes Marshall. La simulation du dimensionment de la chaussée avec le mélange testé a montré un réel avantage sur le mélange traditionnel.

KEY WORDS: pavements, asphalt mixes, asphalt concrete, recycling, tyre rubber.

MOTS-CLÉS: chaussées, mélanges, béton bitumineux, reciclage, caoutchouc du pneu.

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1. Introduction

The manufacture of asphalt concrete mixtures with addition of tyre rubber can be made by the “dry” process in which the crumb rubber is inserted in the mixture as an aggregate portion, or by the “wet” process in which the crumb rubber is added first to asphalt cement and then is incorporated to the mixture.

In the dry process, the crumb rubber is inserted directly into the mix. It thus causes compaction difficulty and leads to loss of one-third of the dynamic modulus in relation to the same mix without crumb rubber [MED 99].

In the wet process, the crumb rubber is previously mixed into the asphalt cement in appropriate equipment. It interacts with the rubber, thus improving the performance of the asphalt concrete similar to polymer modification: i.e. the improvement of aging resistance, the improvement of mixture elasticity [HAN 93; ROB 93] and the use of reduced thickness [SOU 99].

The asphalt cement modification process occurs during an interval of time between a half-hour to one hour and half. This delay can be accomplished in the wet process. The same is not possible in the dry process.

Crumb rubber is not inert and it undergoes change during the time in which it remains in contact with the asphalt cement. This process of modification occurs naturally during the time in which the mixture is transported to the field in a truck until the temperature is reduced. In the laboratory, it is possible to simulate this time delay, thus maintaining the mixture in an oven 10°C below the mix temperature.

With studied mixtures, containing 5.2% of asphalt cement of 60/70 penetration [MED 99], it was noted that the modification time in the dry process is around 60 minutes, evaluating with the void contents, the compression resistance and the conserved resistance after immersion.

1.1. *Justification*

The use of crumb rubber apart from preventing the tyres to become a source of pollution it improves the pavement life span. Such improvement is due to the antioxidants and inhibitors of ultraviolet radiation effects. The rubber contents prolong the asphalt cement life span and reduce the temperature variation sensitivity [HAN 93; ROB 93; FHW 92; AMI 93; CAL 92; CAL 94; DOT 88].

1.2. *Objective*

The objective of this study is to evaluate the structural behaviour of the asphalt concrete mixed with tyres crumb rubber. The crumb rubber is incorporated into the mixture with dry process but pursuing the structural improvements obtained with the wet process by keeping the mixture in an oven.

The study in laboratory sought to find the crumb rubber content that leads to the best asphalt concrete performance.

1.3. *Procedure*

The complete study was developed in the laboratory, adopting the traditional procedure usually applied to manufacture the asphalt concrete specimen following the MARSHALL method with incorporation of different contents of crumb rubber.

After getting the mixes, the materials were put in an oven during one hour under 160°C with the purpose of simulating the time taken to transport of the mixture from the plant to the field.

The experimental mixtures (with crumb rubber) were prepared with different rubber proportions and different asphalt proportions and afterwards compared to the reference mix (without rubber). The same aggregate graduation and the same asphalt cement were used for the sake of allowing such comparisons.

The assessment was based in the MARSHALL parameters, the indirect tensile stress, the fatigue life and the resilient modulus.

2. The materials

2.1. *The aggregates*

Crushed granite has been used as the mineral aggregate of the mixture, being obtained in the region of Florianópolis City (Santa Catarina State). The adhesion of the asphalt to the aggregate has been good

The granular composition adopted in the investigation was prepared according to the specification standards of the Santa Catarina Road Department (DER-SC) (figure 1).

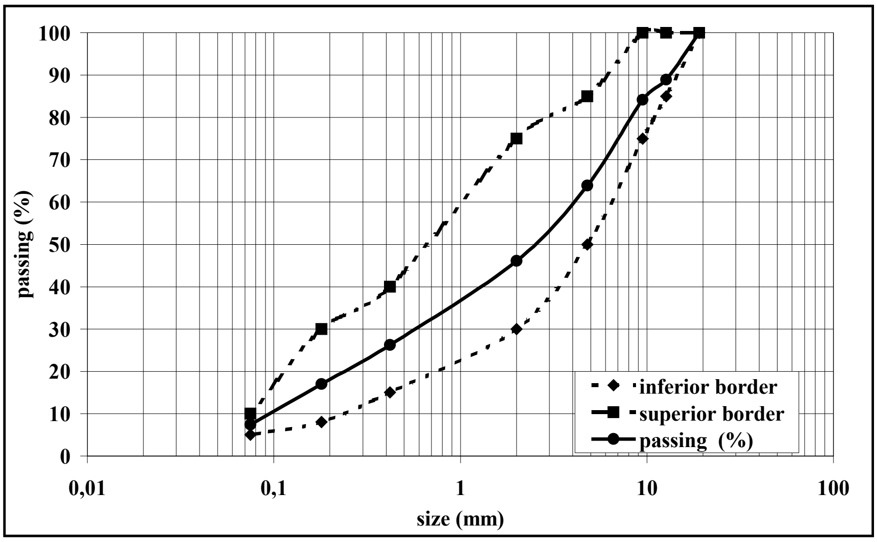

Figure 1. *Aggregate graduation***.**

2.2. ***Asphalt cement***

The asphalt cement used was the CAP 20 (viscosity classification) from the Araucária refinery situated in the Paraná State, with softening point at 48°C and the Saybolt-Furol viscosity 180 s (at 135°C).

2.3. ***Crumb rubber***

The crumb rubber was get from commercial tyre *decoupage*, with a maximum size particle of 2.4 mm and with 70% retained in the sieve of 0.297 mm.

2.3.1. *Micromorphology*

Without following a specific standard procedure the rubber particles are observed through an optical microscope before and after the asphalt cement addition (figures 2 and 3 respectively). The addition of the crumb rubber to asphalt cement was carried out in a similar way to the specimen manufacturing procedure

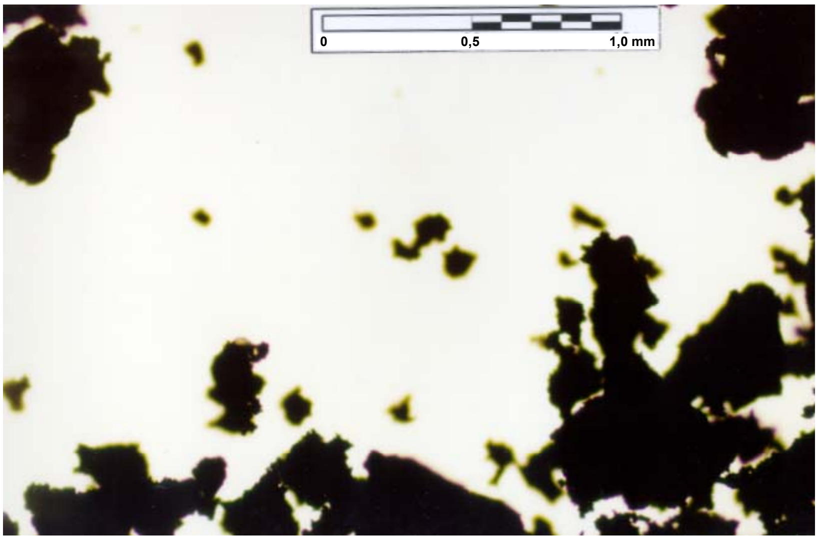

Figure 2. *Crumb rubber before the asphalt cement mixture***.**

3. Laboratory procedures

3.1. *Reference mixture*

The reference mixture was prepared according to the MARSHALL method with the fallowing asphalt cement contents: 4.0%, 4.5%, 5.0%, 5.5% and 6.0%.

The optimum asphalt cement mix was get from analysing the MARSHALL method results, with which new specimens were manufactured to submit to the fatigue and resilience modulus tests. This conventional mixture was named “reference mixture”.

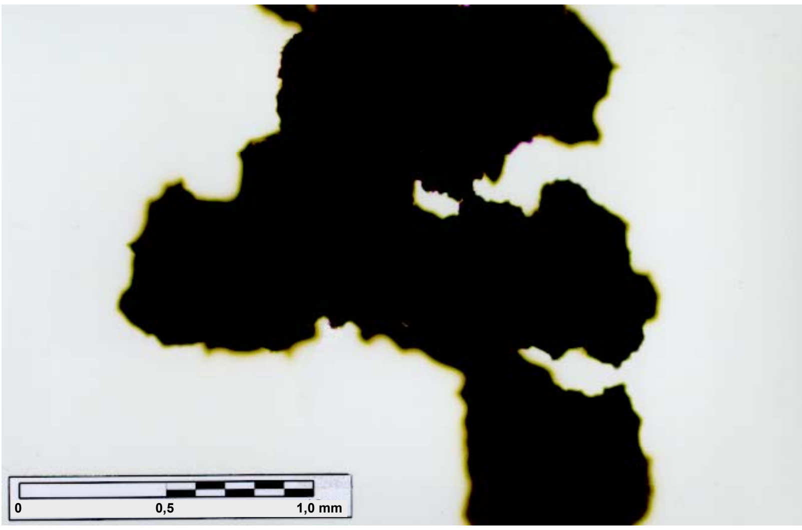

Figure 3. *Crumb rubber after the asphalt cement mixture.*

3.2. *Experimental mixtures*

The experimental mixtures were made with three different amounts of rubber and different asphalt cement contents (table 1). The asphalt cement contents were related to the total weight of the mixture and the rubber contents were related to the aggregate weight.

The specimens for the fatigue and resilient modulus ha been manufactured by using the results of the MARSHALL method and the indirect tensile stress, named experimental mixture (It has been used a minimum of three specimen for each test).

Table 1 – *Experimental Mixtures*

Experimental mixtures	Rubber contents (%)	Asphalt cement contents (%)
Exp 0.7	0.7	3.97 4.47 4.97 5.46 5.96
Exp 1.1	1.1	4.65 5.25 5.84
Exp 0.4	0.4	4.68 5.28 5.88

3.3. *Specimen manufacture*

The MARSHALL specimens were manufactured with 1200 g of weight with 10.2 cm of diameter and with the energy of 75 falls per face.

3.4. *Asphalt cement content*

The asphalt cement content of the reference mixture was set to 4.8%, with the main criterion (the void content on the tendency line) being set to 5.6 %.

The 5.3 % asphalt cement and the 0.7 % rubber contents were chosen by means of the MARSHALL method and the indirect tensile test. This mixture is called "experimental optimised mixture".

The reference and the experimental mixture were submitted to the fatigue and resilience modulus tests.

3.5. Resilience modulus

The resilience modulus was measured with the MARSHALL specimens, with time charge of 0.1 s and rest of 0.9 s, at 25°C.

3.6. *Indirect tensile test*

The indirect tensile test was verified on MARSHALL specimens, according to the National Highway Department – Test Method DNER-ME 138/86 at 25°C.

3.7. *Fatigue*

The fatigue life spans were obtained with the MARSHALL specimens, under controled stress, time charge of 0.1 s and rest of 0.9 s, and the rupture criterion was the division of the specimen in two half.

4. Laboratory results

4.1. *MARSHALL test – conventional mixtures*

The conventional mixture results (without rubber) are presented in figures 4, 5, 6, and 7.

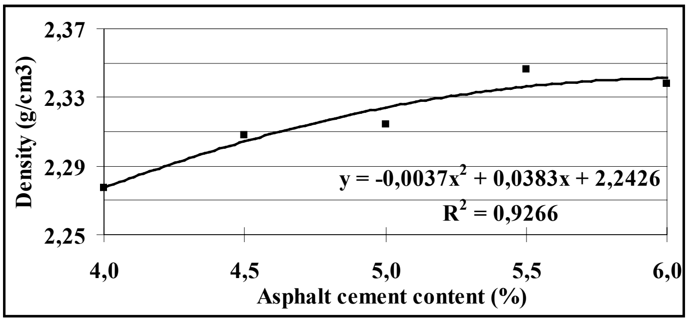

Figure 4. *Density – conventional mixtures*

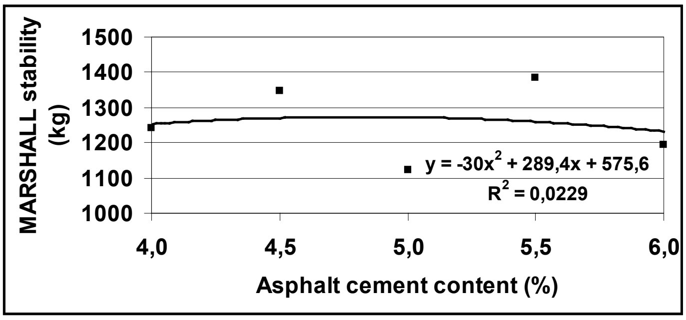

Figure 5. *MARSHALL stability - conventional mixtures*

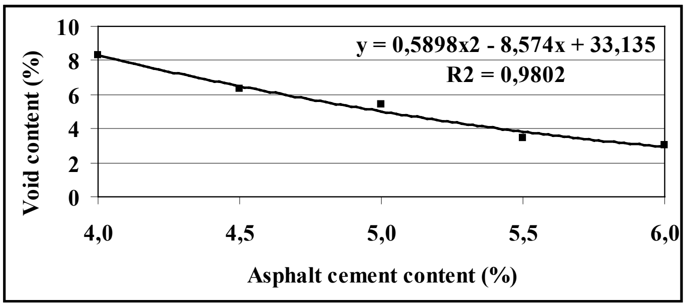

Figure 6. *Void content – conventional mixtures*

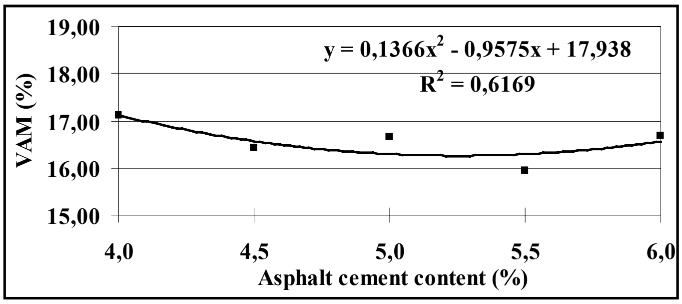

Figure 7. *Void aggregate mineral – conventional mixtures*

4.2. *MARSHALL tests – experimental mixtures*

The MARSHALL test of the mixtures with rubber resulted in the following parameters to take into count in choosing the mixture to the fatigue and modulus tests:

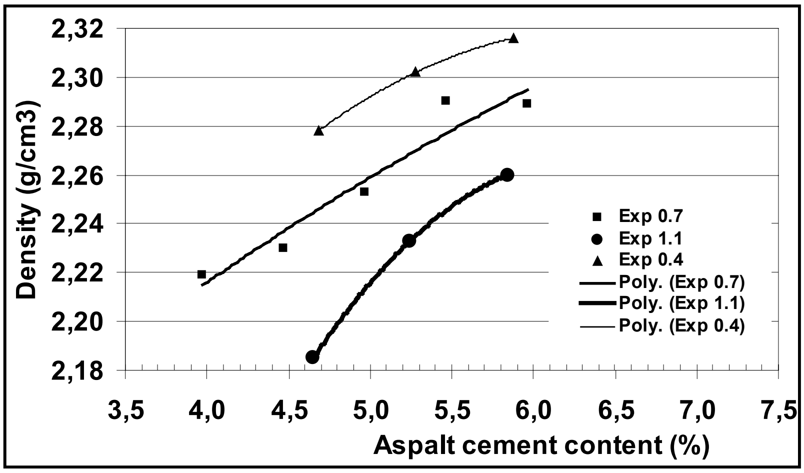

Figure 8. *Density – experimental mixtures*

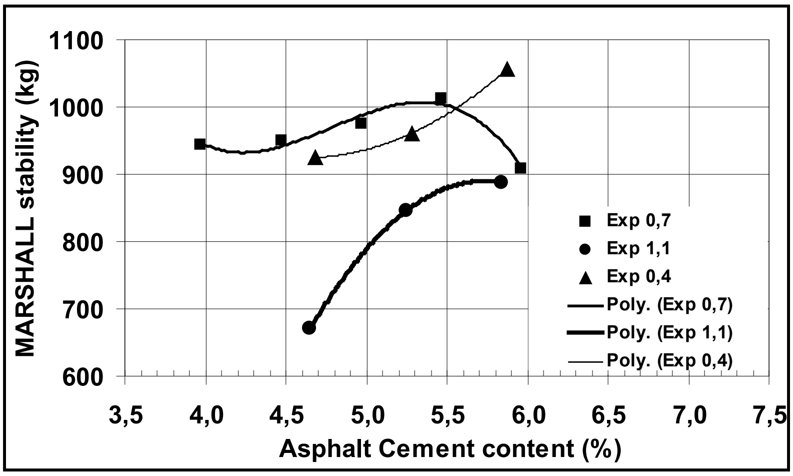

Figure 9. *MARSHALL stability – experimental mixtures*

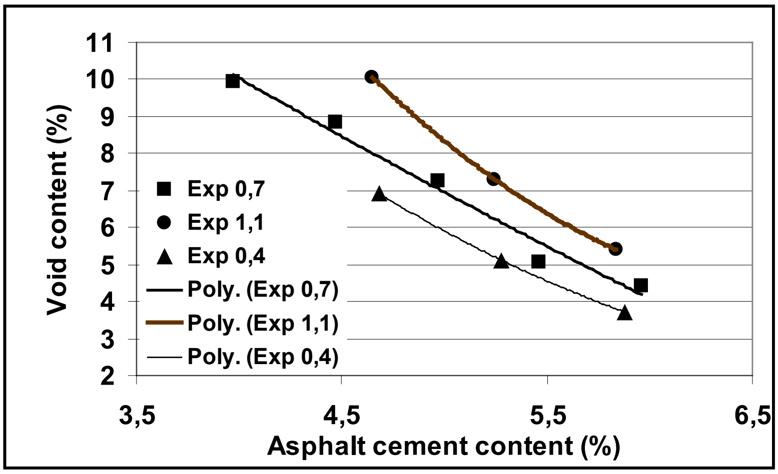

Figure 10. *Void - experimental mixtures*

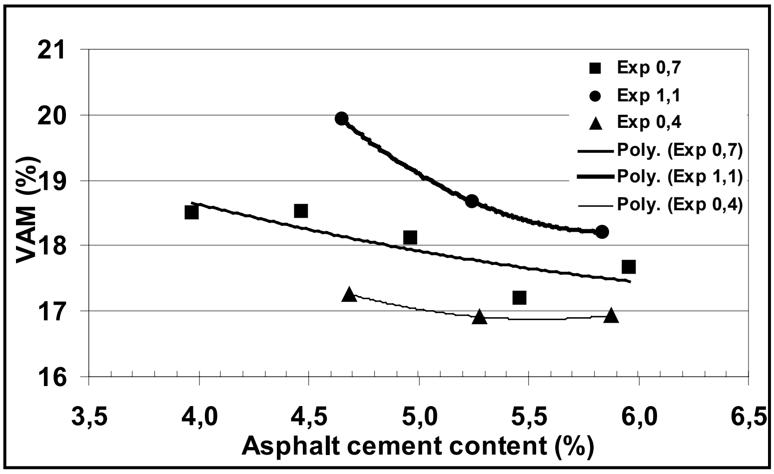

Figure 11. *Void aggregate mineral - experimental mixtures*

4.3. Indirect tensile stress

The indirect tensile stress (figure 12) presented smaller values in relation to the increase of added crumb rubber in the mixture, that is, the increment of crumb rubber did not result in bigger values for the indirect tensile stress.

4.4. Resilience modulus

The resilience modulus and the fatigue tests were made: a) one conventional mixture b) one experimental mixture.

The results of the resilience modulus and the fatigue tests are shown in the tables 3 and 4.

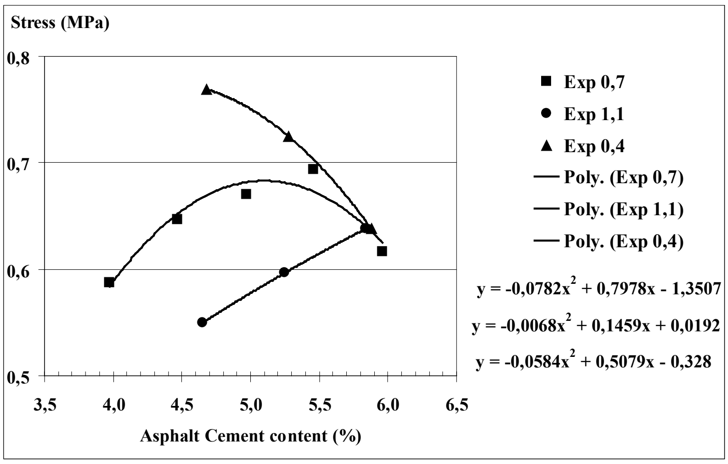

Figure 12. *Indirect tensile stress - experimental mixtures*

Table 3. *Resilient modulus – reference mixture*

Specimens number	Charge (N)	Initial Resilience strain (cm)	Resilience modulus (MPa)	Average (MPa)
2814	5120	0.00106	4306	4314
	5997	0.00124	4322	
2819	4244	0.00106	3569	3630
	5120	0.00124	3691	
2827	5997	0.00088	6117	5563
	6873	0.00124	5008	
			Average	**4502**

Table 4. *Resilient modulus - experimental optimised mixture*

Specimens number	Charge (N)	Initial Resilience strain (cm)	Resilience modulus (MPa)	Average (MPa)
2953	4244	0.0009	3893	3345
	5120	0.0014	3170	
	5997	0.0017	2970	
2967	4244	0.0011	3234	3100
	5120	0.0014	3219	
	5997	0.0018	2845	
2962	4244	0.0018	1992*	2630
	5120	0.0014	3185	
	5997	0.00195	2713	
			Average	**3153**

(*) Eliminated.

4.5. *Fatigue*

The fatigue trend lines obtained with the reference mixtures and the optimised experimental mixtures are shown in the figure 13.

The crumb rubber addition produced a translation of the fatigue trend line. It results higher strain values in relation to the numbers of cycles.

The crumb rubber mixtures fatigue trend lines presented bigger exponent (fatigue trend line grading in log-log scale), showing that the lines are more spaced to larger values of cycles.

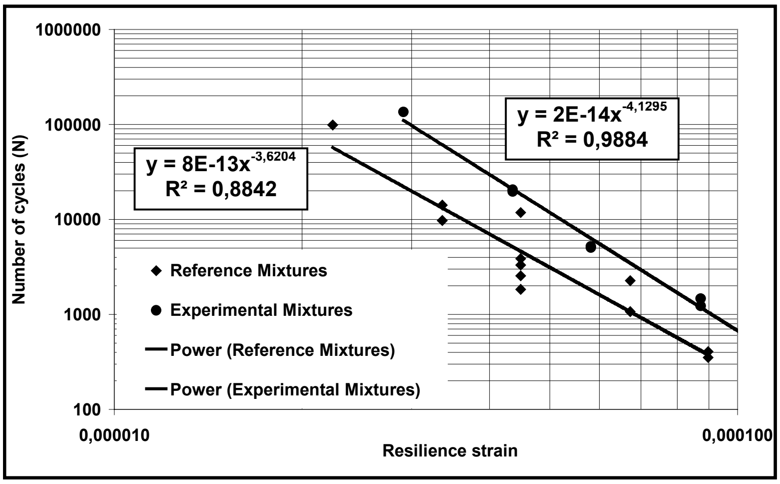

Figure 13. *Fatigue – reference and experimental optimised mixtures*.

5. Simulated design

The comparison between the reference and the experimental mixtures was made with the hypothetical simulated design through the Elsym5 software.

The simulations were made with the same materials and the same coarse thikness, with the variation of the resilience modulus and the fatigue trend line values.

The cycle numbers (N) were obtained without field shift factors (table **5)**.

Table 5. *Pavement structure simulated design*

Structure	Type	Tensile strain	Numbers of Cyles	Increase (%)
1 (small deep)	Reference	0.81 x 10^{-4}	520	
	Experimental optimised	0.96 x 10^{-4}	780	50
2 (medium deep)	Reference	0.62 x 10^{-4}	1368	
	Experimental optimised	0.75 x 10^{-4}	2163	58
3 (medium deep)	Reference	0.48 x 10^{-4}	3457	
	Experimental optimised	0.58 x 10^{-4}	6251	81
4 (big deep)	Reference	0.31 x 10^{-4}	16833	
	Experimental optimised	0.38 x 10^{-4}	35835	113

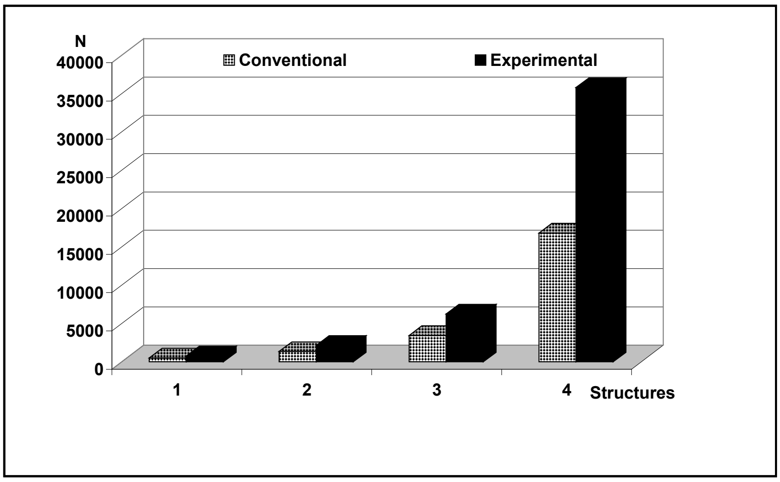

Figure 15. *Simulated design synopsis*

6. Conclusions

In the range of the experiment, the crumb rubber addition showed:

The asphalt mixture density decreases in relation to the crumb rubber incorporations.

The MARSHALL stability presented the maximum tendency to the 0.7 % crumb rubber proportion.

The void and void aggregate mineral contents increased in relation to the increase of crumb rubber contents.

The crumb rubber addition produced a decrease of the tensile stress values.

The experimental crumb rubber mixture presented smaller values of resilience modulus in relation to the reference mixture. It resembles the result observed with the virgin polymers.

The asphalt mixture with crumb rubber addition presented fatigue life span variation less sensitive in relation to the number of cycles.

With the simulated design comparison, the experimental optimised composition showed advantage in relation to the reference composition for all structures. Also, it showed a bigger advantage to the structures submitted to higher solicitation.

7. Acknowledgements

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