ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 10, Issue 10, October 2023

Experimental and Numerical Analysis of the Incorporation of Recycled Tires for Construction Applications

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Abstract— The entire ground transportation system of the human being greatly raised with the industrial revolution in the past centuries. Actually, the construction of high ways, automotive and related complementary industries play an important role in our worldwide economy. This development exploited the use of natural sources, mainly, aggregates for all asphalt layer in civil construction networks, creating a relevant pollution. Consequently, the present communication presents a new proposal asphalt layer by incorporating waste of local pelletized pneumatic tires for the structural use in highways. The optimal proportion of asphalt was numerically and experimentally determined. Once this parameter was set, the pelletized pneumatic was added to the asphalt according to 0.5, 1, and 5 % wt. Each configuration was mechanically characterized by means of the in-plane compression test; a specific characteristic failure mechanism was observed for each configuration. The most attractive mechanical response was observed for 0.5 and 1 % wt. The last was considered as the optimal balance between ecological concern and structural performance. Hence, this configuration was numerically studied by using a commercial finite element software. A good agreement was obtained between the experimental and numerical results, validating the proposed numerical methodology.

Index Terms—Asphalt binder, Numerical simulation, Marshall test.

I. INTRODUCTION

At the end of their useful life, tires are largely translated into environmental problems, since they are dumped in different landfills. Resulting in the contamination of water sources, air, as well as the proliferation of parasites that cause many diseases [1–5]. An eco-friendly alternative is the reuse of rubber from recycled tires in other applications. Among them, the use of rubber for the elaboration of flexible pavements stands out [6].

Flexible pavements are the most widely used because of their low cost, high ride quality, easy maintenance, and high skid resistance [7]. However, mass traffic movement, pavement construction problems, climate change and in most cases, the use of base bitumen without modification leads to problems in terms of rutting, fatigue and low temperature cracking [2]. Therefore, some authors concurred that the combination of traditional asphalt with other materials, whether natural or synthetic, can contribute to the improvement of mechanical properties considering appropriate materials, methods and geographical factors [2–5,8–12].

The most common methods for asphalt mix design are: Marshall, Hveem and Superpave [13]. For the present investigation, the Marshall test was considered and with regard to the numerical simulation tests, the Finite Element Method (FEM) was chosen by using a commercial software FEM, since according to research, the FEM method allows establishing models of asphalt mixtures with high tire rubber content, as well as predicting the compatibility between recycled rubber and asphalt binder [14–16]. The objective of this communication is to present a comparison of the results obtained by experimental and numerical tests performed on a batch of asphalt specimens in combination with rubber derived from recycled tires, after a granulometric treatment.

II. MATERIALS AND METHODS

A. Materials and Processing for Experimental Campaign

Stone aggregates provided by the company ROOKAZUL were used in the formulation of the asphalt, which had a nominal maximum size for coarse aggregates 3/4". The fine aggregates were sand and stone dust. Type AC-20 asphalt provided by ASFALTAR EP was used. Rubber powder was also used, which was provided by the company RENOVALLANTA.

The granulometric test was performed according to the ASTM C136-06 and INEN 2680:2013. The maximum nominal size of stone aggregates used was 19 mm, and from which the granulometric test was performed for coarse and fine stone aggregates, as well as for rubber powder from recycled tires, considering a 1⁄2 " band. The determination of the specific gravities for coarse and fine aggregates were performed based on the guidelines of the ASTM C127-15 and ASTM C128-07, hence: oven dry gravity (SH), Surface Saturated Surface Dry (SSS) gravity, Apparent gravity (Ap), and from this the absorption for coarse and fine stone

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

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aggregates. An additional test was carried out to determine the resistance of coarse aggregates to fragmentation (abrasion) in of the Angels machine (ASTM C131/C131M-14). Finally, based on ASTM D70-03, the density of AC-20 asphalt was determined by means of the pycnometer test and with respect to the other specifications of the asphalt used, these are described in Table 1 according to ASTM D3381-09.

Table I: Viscosity graded AC-20 asphalt cement requirements at 60°C.

Determined parameter	Value
Absolute viscosity (60°C Pa s)	2000±400
Kinematic viscosity (135°C mm^2/s)	210
Pentration rate (25°C mm)	40
Solubility in Trichlorethylene (%)	99
Flash point by Cleveland open cup (°C)	232
Maximum absolute viscosity (60°C Pa s)	10000
Ductility (25°C cm/min)	20

Regarding the asphalt mix and the preparation of the specimens with 64 mm in height and 102 mm diameter, the asphalt-stone aggregate mix was prepared by the Marshall Method [17]. Hence, the asphalt mix design was carried out according to the Marshall method, by setting heavy traffic. Consequently, three specimens were prepared for different values of wt%. of asphalt, based on the ASTM D 5589-96 and NEVI - 12 standards. For the asphalt-stone aggregates mixture, the stone aggregates and asphalt were placed in the oven at a temperature between 60 and 120 °C. Considering mass values for the aggregates according to the respective asphalt percentages that were poured into the mixture (5, 5.5, 6, 6.5 and 7 wt%). Proceeding to uniformly mix the stone aggregates (until the entire mixture takes on a uniform color) according to the respective asphalt percentages in approximately 3 to 5 minutes while maintaining a temperature between 120 and 140 °C. Part of the mixture of each percentage of asphalt was tested to determine its maximum theoretical specific gravity in bituminous mixtures (RICE). For the production of specimens, the uniform mixture was placed in the preheated Marshall molds for its respective compaction, trying to maintain a temperature between 130 and 140 °C. The mixture was compacted with the support of the Marshall hammer, making a total of 150 blows, 75 blows on each side of the specimen. The specimens were left to rest for 24 hours and were then extracted from their respective molds with the help of a mechanical extruder. The three specimen configurations were immersed in a water bath for 30 min at a temperature of 60 °C.

Once the specimens were made for the different percentages of asphalt, the following values were determined: unit weight, BULK density, relative density, percentage of voids of the mineral aggregate (%VMA), percentage of voids filled with asphalt (%VFA), percentage of air voids (%VAC) and with the help of the Marshall testing machine, the specimens were broken to determine stability and flow values. Once, the stability and flow values were obtained with the Marshall machine, as well as the corresponding specific gravity values of the materials involved in the asphalt-stone aggregate mixture, the optimum asphalt was determined and then the asphalt was mixed with the rubber by the dry process, taking into account that this mixture can be made by dry or wet process [18]. The procedure for the elaboration of specimens with rubber granules from recycled tires was developed according to the following standards: ASTM D 5589-96, NEVI - 12 and INEN 2680:2013. Similar to the asphalt-stone aggregates mixture, with the only variable that a time was considered for the digestion of the rubber. With respect to the aggregate-asphalt-rubber mixture, specimens were made considering fine aggregate substitution values of 0.5, 1 and 5 wt%. Once the specimens were made for the different percentages of rubber granules from recycled tires, the following values were determined: BULK density, maximum relative density, VMA, VFA, VOIDS, and using Marshall testing machine, the stability and flow values were determined. Fig. 1 a summarizes some aspects of the experimental campaign detailed above, for the design of an asphalt mix by the Marshall method.

(a)

(b)

Fig. 1 Procedure of the experimental campaign developed. a) Asphalt mix involving rubber granules from recycled tires, b) Compressive test of a specimen.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

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B. Numerical Simulation Campaign of the In-Plane compression test

Regarding the numerical simulation campaign of the in-plane compressive test for the proper ecological asphalt configuration determined at the end of the experimental campaign. The FEM were set under a standard simulation (quasistatic process), implementing, 95 MPa, 0.35 and 30° for Young modulus, Poisson coefficient and dilatation angle, respectively. This entire characterization of the asphalt material was carried out during the developing of the present research. The specimen was modeled with deformable solid element, while the testing instrument was simulated using shell solid element. The FEM employed less than 30 minutes to predict the compressive response of the optimal asphalt specimen configuration.

III. RESULTS AND DISCUSSION

A. Experimental And Numerical Campaign

In Fig. 2 is summarized the compendium of the experimental campaign, hence, as the value of the wt% of the rubber increases, the values of: voids, VMA and flow increased, while the values of: unit weight and stability decrease. For the variables of: voids, VMA, stability and flow, it can be said that, for a percentage of 0.5 wt% of rubber, the established ranges are met and even with regard to stability it is higher than a mixture without rubber content. As the wt% of rubber increases, the mixture becomes less permeable since the voids increases, it has a greater tendency to deformation under the action of loads, since the stability value decreases and the flow value increases, that is, the Marshall stiffness decreases [17,19–21]. High values of stability and flow ratio indicate an adequate design in the asphalt mix by the Marshall method [21].

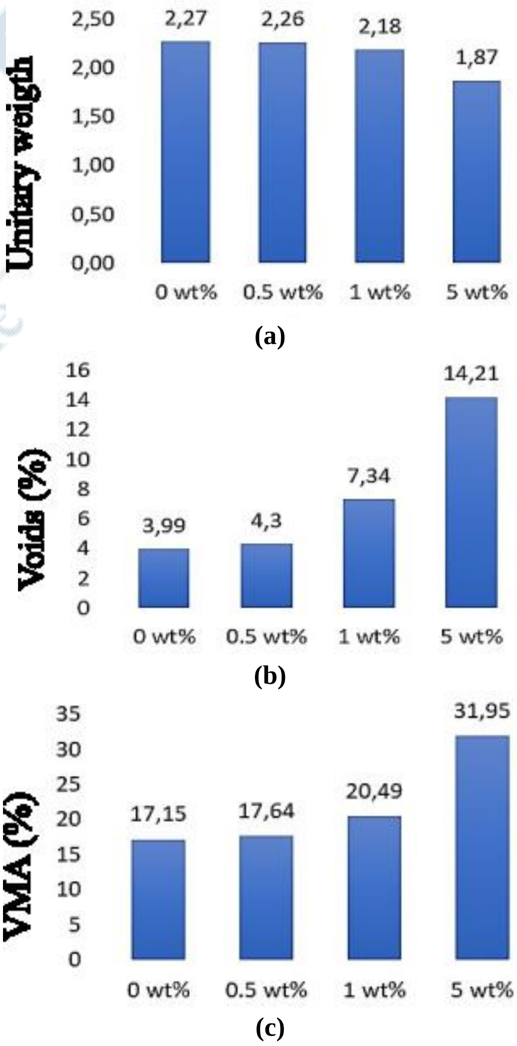
Fig. 3 shows the load-displacement graphs obtained with the Marshall apparatus. The average for each case was determined: 0.5 wt% of rubber (continuous light blue curve), 1 wt% of rubber (continuous orange curve) and 5 wt% of rubber (continuous red curve). Their standard deviations (shaded areas), compared with the average and standard deviations in which the optimum asphalt was obtained with 6.5 wt% (continuous black curve and gray shade). Analyzing Fig. 3, it can be indicated that in all cases a high repeatability was obtained between the samples of each configuration. Observing a reduced area of standard deviation as a general behavior of the samples. Specifically, a high reduction in the standard deviation is observed when the samples experience the largest displacements. For 0.5 wt% rubber around 3mm, for the best around 2.5mm, and for 1 and 5wt% around 4.5mm. Comparing the color curves: light blue, orange and red in Fig. 3, it can be seen that as the value of wt% increases, the resistance that a specimen can withstand before breaking is lower, while the displacement before breaking is higher Translated into terms of Marshall stiffness, it would be a lower Marshall stiffness as the wt% increases.

IV. CONCLUSION

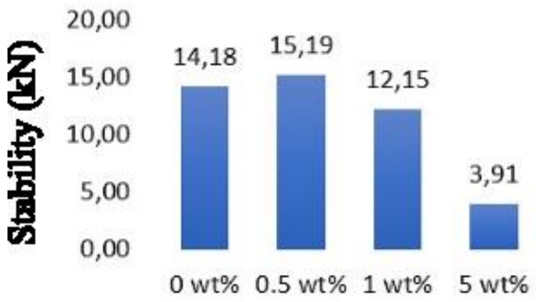
The materials used complied with the parameters of granulometry, specific gravities, absorption and abrasion, for the design of an asphalt mixture by the Marshall method for heavy traffic. However, it was not possible to obtain tire rubber granules under the conditions required by the standards. Laboratory instruments were also not available to perform the corresponding tests.

An increase in the wt% tire rubber content decreases the stability and increases the flow, voids and VMA. The asphalt mixture with a value of 0.5 wt% of recycled tire rubber granules presented better results and, due to the values obtained for stability, flow, void and VMA, it fits the mixture design by the Marshall method for heavy traffic as established in NEVI-12.

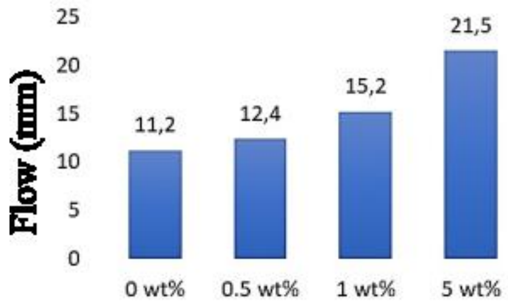
Using commercial FEM software, it was possible to obtain a force-displacement curve very similar to those obtained by the experimental method, so it can be said that it is possible to predict the mechanical behavior of an asphalt layer.



ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 10, Issue 10, October 2023



(d)



(e)

Fig. 2 Asphalt - stone aggregate mix design graphs according to the configuration of the specimen with respect to the wt% configuration.

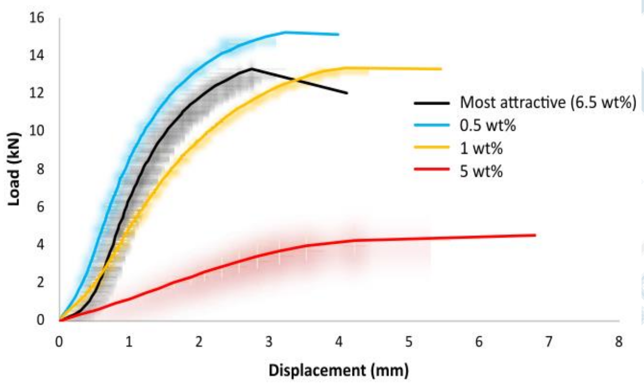


Fig. 3 Load-displacement curves obtained by the Marshall method. The solid lines represent the batch average of samples from each case and the respective shaded areas the standard deviation.

REFERENCES

[1] Saberian M, Li J, Perera STAM, Ren G, Roychand R, Tokhi H. An experimental study on the shear behaviour of recycled concrete aggregate incorporating recycled tyre waste. Constr Build Mater 2020;264. https://doi.org/10.1016/j.conbuildmat.2020.120266.

[2] Badughaish A, Wang J, Hettiarachchi C, Xiao F. A review on the crumb rubber-modified asphalt in the Middle East. J Mater Cycles Waste Manag 2022;24:1679–92. https://doi.org/10.1007/s10163-022-01455-0.

[3] Yu H yang, Deng G sen, Wang D yi, Zhang Z yu, Oeser M. Warm asphalt rubber: A sustainable way for waste tire rubber recycling. J Cent South Univ 2020;27:3477–98. https://doi.org/10.1007/s11771-020-4467-y.

[4] Xue H, Cao Y, Liu Q, Zhang H, Zhang M. Stability Evaluation and Mechanism of Asphalts Modified With Various Rubber Powder Contents. Front Mater 2021;7. https://doi.org/10.3389/fmats.2020.622479.

[5] Parra SA, Diaz FV, Acevedo CJS, Cardenas JCR. Experimental evaluation of different additives applied in a hot dense mix asphalt MDC - 19. 2021 7th Congreso Internacional de Innovacion y Tendencias en Ingenieria, CONIITI 2021 - Conference Proceedings, Institute of Electrical and Electronics Engineers Inc.; 2021. https://doi.org/10.1109/CONIITI53815.2021.9619665.

[6] Bressi S, Fiorentini N, Huang J, Losa M. Crumb rubber modifier in road asphalt pavements: State of the art and statistics. Coatings 2019;9. https://doi.org/10.3390/COATINGS9060384.

[7] Zarei S, Ouyang J, Yang W, Zhao Y. Experimental analysis of semi-flexible pavement by using an appropriate cement asphalt emulsion paste. Constr Build Mater 2020;230. https://doi.org/10.1016/j.conbuildmat.2019.116994.

[8] Jitsangiam P, Nusit K, Phenrat T, Kumlai S, Pra-ai S. An examination of natural rubber modified asphalt: Effects of rubber latex contents based on macro- and micro-observation analyses. Constr Build Mater 2021;289. https://doi.org/10.1016/j.conbuildmat.2021.123158.

[9] Chai C, Cheng Y, Zhang Y, Zhu B, Liu H. Mechanical properties of crumb rubber and basalt fiber composite modified porous asphalt concrete with steel slag as aggregate. Polymers (Basel) 2020;12:1–16. https://doi.org/10.3390/polym12112552.

[10] Tan Z hua, Wang J jing, Shi Z ning. Laboratory investigation on effects of organic montmorillonite on performance of crumb rubber modified asphalt. J Cent South Univ 2020;27:3888–98. ttps://doi.org/10.1007/s11771-020-4578-5.

[11] Sienkiewicz M, Borzędowska-Labuda K, Wojtkiewicz A, Janik H. Development of methods improving storage stability of bitumen modified with ground tire rubber: A review. Fuel Processing Technology 2017;159:272–9. https://doi.org/10.1016/j.fuproc.2017.01.049.

[12] Umar Munir M, Elnour A, Huda S, Zeiada W. Activated Crumb Rubber Modified Binder as a Sustainable Paving Material: Pavement Performance Consideration; Activated Crumb Rubber Modified Binder as a Sustainable Paving Material: Pavement Performance Consideration. 2020.

[13] Garnica P, Delgado H, Sandoval C. ANÁLISIS COMPARATIVO DE LOS MÉTODOS MARSHALL Y SUPERPAVE PARA COMPACTACIÓN DE MEZCLAS ASFÁLTICAS. 2005.

[14] Lushinga N, Dong Z, Cao L, Yang C, Ullah S. Fatigue characteristics and environmental sustainability of rubber asphalt composite modified asphalt mixtures incorporating nanosilica. Constr Build Mater 2022;346. https://doi.org/10.1016/j.conbuildmat.2022.128382.

[15] Zhou X, Chen S, Jin D, You Z. Discrete Element Simulation of the Internal Structures of Asphalt Mixtures with High Content of Tire Rubber. Lecture Notes in Civil Engineering, vol. 164, Springer Science and Business Media Deutschland GmbH; 2022, p. 425–39. https://doi.org/10.1007/978-3-030-77230-7_32.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 10, Issue 10, October 2023

[16] Zheng W, Wang H, Chen Y, Ji J, You Z, Zhang Y. A review on compatibility between crumb rubber and asphalt binder. Constr Build Mater 2021;297. https://doi.org/10.1016/j.conbuildmat.2021.123820.

[17] Garnica P, Delgado H, Gómez J, Romero S, Alarcón A. ASPECTOS DEL DISEÑO VOLUMÉTRICO DE MEZCLAS ASFÁLTICAS. 2004.

[18] Pablo J, Ramírez R. Diseño de mezcla asfáltica con asfalto caucho tecnología GAP GRADED para la ciudad de Bogotá. 2015.

[19] Meneses P, Torres R. Análisis de las propiedades mecánicas de la mezcla asfáltica modificada con granulado de neumático reciclado, incorporado como reemplazo parcial del agregado fino. 2021.

[20] Terán Luis. DISEÑO DE MEZCLAS ASFÁLTICAS EN CALIENTE UTILIZANDO AGREGADOS DE LA MINA CASHAPAMBA CON METODOLOGÍA MARSHALL. 2015.

[21] Rondón H, Reyes F. Pavimentos Materiales, construcción y diseño. 2015.