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Abstract. Reclaimed asphalt pavements are obtained from existing pavements through recovery techniques and are used for new asphalt mixtures production with the inclusion of virgin aggregates and asphalt cement, constituting environmentally friendly mixtures at a lower total cost, by requiring fewer quantities of new materials. This research, unlike the studies found on the subject, focuses on the study of reclaimed asphalt pavement by analyzing its granulometric distribution and asphalt cement content. For this purpose, representative reclaimed asphalt pavement samples were taken from four Colombia cities, to verify their heterogeneity. The obtained reclaimed asphalt pavement was analyzed in the laboratory, to obtain the material granulometric distribution, through extraction and asphalt content tests, following Colombian regulations from the "Instituto Nacional de Vías". The results show that the granulometry of all cities has a central tendency (average) that moves towards an upper limit in the 2 mm particles. When analyzing the granulometry separately of the four cities, it is observed that they present a different trend in their granulometry, which shows their heterogeneity. The asphalt cement content presented values between 4.0% and 5.0%.

1. Introduction

Millions of tons of reclaimed asphalt pavements (RAP), a product of the milling of the roadways, are discarded in the world, product of the milling of the roadways that contain it. A fraction, of these milled materials, is reused for the elaboration of new mixtures, either for later use of asphalt layers or as stabilized bases. The remaining material is taken to landfills which generate a strong environmental impact. The RAP that is milled varies in its size and composition depending, among other factors, on the aggregates source (quarry, river, or combination of both), granulometric composition (material size and distribution), asphalt content, characteristic of asphalt, degree of aging of the mixture (caused by external agents such as climatic conditions during service years), and traffic, making RAP a heterogeneous material.

The procedure and equipment used in the roadways for the extraction of RAP also influence its properties. In the milling process, the size of the aggregates is reduced due to the mechanical degradation to which they are subjected, being able to obtain grinding, crushed, or in large pieces. Han J, *et al.* [1] took milled RAP from three projects, separating aggregate from asphalt cement through ignition and centrifugation processes. They found that the aggregates obtained, by both methods, were reduced in size compared to the size of the aggregates used in the initial mix, reporting a 4% increase in the fine

particles that passed the 75-micron sieve. On the other hand, Solaimanian and Tahmoressi [2] took different sizes of RAP and determined the influence that the variation of these sizes has within a new mixture while using 35%, 40%, and 50% RAP fractions. They found that using higher percentages of this material increased the variation in the new mixture gradation; They also reported that when using RAP from different sources, the new mixtures void content increased by increasing the RAP percentage used.

Other investigations carried out on RAP and on new mixtures produced with it, focus on the study of the new mixtures mechanical resistance and durability parameters, with different RAP contents, which vary from 10% to 100%, such as [3-10]. In addition, the mechanical behavior of recycled mixtures has been studied regarding the content of voids and Marshall stiffness [11-13]. In the same way, researchers such as Lee, *et al.* [14] and Silva, *et al.* [15] have reported studies regarding permanent deformation in recycled mixtures, and fatigue Izaks, *et al.* [16]. The few studies on the RAP granulometric composition and its influence on the behavior of mixtures generate uncertainty in the determination of the required percentages of RAP and new components (stone aggregate and asphalt cement) in the manufacture of hot mix asphalt (HMA).

Therefore, this research, unlike others, aims to deepen the study of RAP mixtures, demonstrating the heterogeneity in the composition of the materials that compose them. This is the first stage, and fundamental basis, for an investigation that is carried out on the influence that this variability has on the manufacture of new HMA.

2. Materials and methods

For the present research, to verify the heterogeneity of the asphalt mixtures, a total of 31 RAP samples were taken from 4 cities in Colombia. Asphalt content extraction test (INV E-732-13) [17] and aggregate granulometry test (INV E-782-13) [18] were carried out on each sample, to determine the optimum asphalt content and the granulometry of the mixtures.

To perform these tests, approximately 1200 grams of RAP material were taken per test, subjecting it to drying and subsequent centrifugation process, for the extraction of asphalt, as referred to in the standard INV E-732-13 [17]. After asphalt extraction from the mixture, the aggregates were taken to the oven, weighed, and washed on the No. 200 sieve to be dried again and subjected to sieving (INV E-782-13) [18]. Once the previous process was finished, the characteristic granulometric curve of each mixture was determined.

The process was repeated for all the materials from each city. Subsequently, the mean of the granulometry and the percentage of asphalt cement that make up the RAP was determined, for the evaluated cities of Colombia. Through a statistical and variance analysis (unifactorial or one-way analysis of variance (ANOVA)), the optimal asphalt content of the four cities and the most representative granulometry were determined.

3. Results and discussion

After performing the tests to extract the asphalt content in all the samples, different granulometries were found for the four cities, verifying that they are heterogeneous. Taking the results for each of the granulometries, the mean was determined for all the cities whose results are shown in Table 1.

The aggregates show a trend towards the upper limit of the INVÍAS [18] regulation for an MDC-19 asphalt mix, which means that it tends to be a fine material. This is related to the milling process by which the RAP samples were obtained. Milling affects the particle size of the aggregates, with the consequent increase in fine particles content. Table 2 shows the dispersion parameters of the four Colombia cities analyzed.

With the results of the mean values of each size in the granulometries of the four cities, an ANOVA was performed. Table 3 shows the results of F (statistic), F critical, and significance p-value. F values greater than F critical, and significance values less than 0.05 are observed; this indicates a greater statistical significance and allows us to conclude that there is heterogeneity in the aggregate particle size compared among the four cities analyzed.

Table 1. Results of the mean in the granulometry of all the cities.

Sieve	Sieve (mm)	Average	Inferior limit [18]	Superior limit [18]
3/4"	19.000	98.0	100	100
1/2"	12.700	89.4	80	95
3/8"	9.520	80.5	70	88
Nº4	4.750	61.6	49	65
Nº10	2.000	45.9	29	45
Nº40	0.425	27.8	14	25
Nº80	0.177	18.3	8	17
Nº200	0.074	9.2	4	8

Table 2. Granulometric dispersion parameters for the analyzed cities.

Passing sieve	Dispersion measurements of the different sizes of particles							
	3/4"	1/2"	3/8"	Nº4	Nº10	Nº40	Nº80	Nº200
Average	98.03	89.42	80.54	61.58	45.94	27.81	18.27	9.20
Variance (S^2)	2.46	22.54	25.48	24.11	13.34	7.60	3.00	1.20
Standard deviation (SD)	1.57	4.75	5.05	4.91	3.65	2.76	1.73	1.09
Coefficient of variation (cv)	1.60	5.31	6.27	7.97	7.95	9.91	9.48	11.89

Table 3. Results of the analysis of variance (ANOVA) in the granulometries of the four cities.

Passing sieve	No. ¾"	No. ½"	No. 3/8"	No. 4	No. 10	No. 40	No. 80	No. 200
F	12.35	4.578	7.797	13.043	24.465	44.237	51.927	17.397
F critical	2.96035							
p-value	<0.05							

The asphalt cement was extracted from the asphalt mixtures and the asphalt content with respect to the total mixture was determined. Based on the asphalt content extracted in the RAP, calculation of the mean and the dispersion parameters (variance, standard deviation, and coefficient of variation) was performed. Table 4 shows that the mean asphalt cement content oscillates around 4.61%, with a standard deviation of 0.61.

Subsequently, an ANOVA was carried out on the results of the asphalt extractions of the RAP of the roadways for the four cities studied. The results of the ANOVA show an F = 12.055 greater than the F (critical) = 2.975, and a significance of p-value < 0.05. A significance below 0.05 is observed, which represents greater statistical significance, indicating variation in the means of the asphalt cement values obtained in the four cities.

Table 4. Dispersion parameters in the asphalt content.

Dispersion measure	Asphalt content (%)
Average	4.61
Variance (S^2)	0.37
Standard deviation (SD)	0.61
Coefficient de variation (cv)	13.16

4. Conclusions

The tests of "Instituto Nacional de Vías" performed on the asphalt extraction process and granulometry of the aggregate particles reports that the mean of the granulometry extracted from the four evaluated cities shows a central tendency within the granulometric band for an MDC-19 mixture in the sizes of the aggregates that pass the No. ¾" sieve to No. 10 sieve. On the contrary, for the aggregates that pass from No. 10 sieve to No. 200 sieve, the trend is above the upper limit of the granulometric range for an MDC-19 mixture, indicating a higher fine fraction in the reclaimed asphalt pavements. This higher fraction is due to the mechanical wear to which the material has been subjected when it is extracted from the roadway, which is variable depending on the methodology used in the field.

The analysis of variance showed significant differences in the mean values of the size of the aggregate particles extracted from the reclaimed asphalt pavements in the four cities, demonstrating that it is a heterogeneous material. The heterogeneity is also reflected in the percentages of asphalt cement extracted from the reclaimed asphalt pavements of the cities evaluated, some above the average and others below it. The mean asphalt cement content, in the reclaimed asphalt pavements mixes evaluated, is on the order of 4.6%. The heterogeneity in the composition of the aggregates and the asphalt cement content are parameters to consider when designing a new asphalt mix that includes reclaimed asphalt pavements particles.

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