Hot mix asphalt using C&D waste as coarse aggregates

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Abstract

This article evaluates the possibility of designing hot asphalt mix road pavements using Construction and Demolition Waste as coarse recycled aggregates. The percentages of recycled aggregates used in the mixtures were: 0%, 20%, 40% and 60%. Cement and lime were used as fillers. The mixtures made with coarse recycled aggregates complied with the Marshall technical specifications for low volume roads. The mixtures also showed good resistance to permanent deformation evaluated by means of wheel tracking tests. Nevertheless, the mixtures made with RA may have insufficient durability due to their high susceptibility to water action which was evaluated using stripping tests.

Key words: Reutilization (C), Mechanical (E), Adhesion (I).

1. Introduction

Construction and demolition waste (C&D waste) is produced by the construction of new buildings or the demolition of existing structures and is mainly composed of materials which can be reused or recycled. They are generally known as "rubble". These materials are produced in large quantities, with their volume exceeding domestic waste. Their pollutant power is relatively low. In contrast, however, their visual impact is often high, owing to the sheer volume of space they occupy in addition to the lack of environmental control carried out on the lands earmarked for the deposit of these materials. In Spain the government is currently looking for ways to reuse this type of waste, and thus diminish the economic and environmental impact that it causes. In the future, recycled aggregates from C&D waste could act as substitutes for primary aggregate extraction to a much greater

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extent than the way they are currently being used. There is a potential for these materials to be crushed and used as recycled aggregates (RA) in applications such as road base and subbase construction.

To date only a small number of investigations have dealt with the use of RA in hot mix asphalt (HMA). According to Shen and Du [1,2], the performance of HMA with coarse RA is related to the their heavily crushed face, which contributes to the internal friction for permanent deformation resistance. From this point of view, HMA made with coarse RA showed a better performance in terms of permanent deformation and stiffness than HMA elaborated with only natural aggregates (NA). Besides, HMA made with coarse RA satisfied the Taiwan Agency´s stripping test requirements [2]. In keeping with these authors, Aljassar and Al-Fadala [3] reported that HMA produced using aggregates from C&D waste met all the requirements of the Kuwait specifications: Marshall Parameters, permanent deformation and stripping. Wong et al [4] observed that the mechanical and volumetric properties of mixtures containing RA achieved a slightly better performance than conventional mixtures. They considered it feasible to use waste concrete as partial aggregate substitution in HMA. However, no test of any kind was carried out to evaluate its sensitivity to water action. Also, Mills-Beale and You [5] researched the mechanical and volumetric properties of HMA made with different % of RA. When the % of RA was increased from 0% to 75%, the stiffness decreased and the rutting failure potential increased. Even so, according to these authors, C&D waste is capable of serving as a useful replacement in HMA roadways where traffic loads are minimal. They were able to design HMA mixes which satisfactorily resist moisture and water-related damage (stripping). Nevertheless, they revealed that as the % of RA increased, the degree of moisture susceptibility of the HMA mixes also increased. On the other hand, Paranavithana and Mohajerani [6] observed that the volumetric properties (except the % of air voids), resilient modulus and creep values of asphalt specimens containing coarse RA were relatively low compared with the values found for similar specimens made with only NA. Nonetheless, these properties were within the recommended acceptable limits. However, when they evaluated the stripping behaviour, a 34% loss of tensile stress in mixtures with RA was observed. According to these authors, this result was due to high water absorption and the easy separation of the mortar adhered to the RA. Finally, Pérez et al [7,8] found that HMA made with 50% of RA offered mechanical properties that are comparable to mixtures that contain only NA. They designed flexible sections pavements for low volume roads which are feasible merely from a structural point of view. Unfortunately, HMA containing RA had a considerably high stripping potential. Nonetheless, RA was found to be potentially usable in asphalt mixtures if higher quality materials are selected and the resistance to water is improved. Consequently, some researchers [1-5] have reported that HMA made with RA exhibited adequate durability and volumetric and mechanical properties. In contrast, other researchers [6-8] have observed that although, at first, HMA made with RA presented good volumetric and mechanical results, due to the action of water, it proved to have insufficient durability. As a result, in this line of investigation there are controversial opinions among researchers. For this reason, the aim of this work is to evaluate the technical possibility of designing HMA pavement roads with coarse RA using cement and lime fillers.

2. Materials and Methods

2.1. Characterisation of basic materials

The basic materials were characterised in accordance with the Spanish technical standards NLT [9] (Tests for Roads Materials) and the UNE-EN standards [10]. The mixtures were designed according to the Spanish General Technical Specifications for Roads, also known as PG-3 [11].

Aggregates

The NA was schist supplied by a quarry in fractions of 0/6, 6/12 and 12/25 mm. The rock is composed of quartz (35%), albite (30%), mica (20%) and chlorite (15%). The NA complied with the Spanish specifications (Table 1). On the other hand, the C&D waste plant produces an RA 0/40 mm fraction with the following composition in weight: concrete (72.5%); stone (21.5%); miscellaneous bituminous (4%), ceramic materials (1%), and some impurities such as clay, metals, wood, plastics, rubber and gypsum plaster (1%). Figure 1 shows the RA grading curve. The RA did not comply with the Los Angeles coefficient PG3 specification (Table 1) due to the mortar attached to the RA (Figure 2). The high water absorption coefficient value was also due to the attached mortar [12].

Filler

Two kinds of fillers were used. Portland cement with the Blaine surface area equal to 3350 cm^2/g and specific gravity equal to 3.12 g/cm^3 and hydrated lime with a specific gravity equal to 2.20 g/cm^3 at 20ºC and apparent density of 380 g/l.

Asphalt

The asphalt used was 50/70 with a penetration grading of 69 and a softening point with the ring and ball method equal to 48.5º C. Pfeiffer's penetration index was equal to -0.8 and the density was 1.03 g/cm^3. It was confirmed that the asphalt complied with all the Spanish specifications.

2.2. Mechanical tests

Marshall

Eight AC 22 base course mixtures were designed with the Marshall Method [13] with 0, 20, 40 and 60% RA: four HMA were made using 4.75% cement filler and four HMA using 3.75% NA filler plus 1.00% lime filler. Table 2 shows the grading curve selected. For each HMA series of cylindrical samples were made (75 blows per side) with different asphalt percentages. The following parameters were obtained: Voids in Mineral Aggregate, VMA (%); Air Voids in Compacted Mixture, Va (%); Voids Filled with Asphalt, VFA (%); Flow Value, F (mm); Stability, S (kN); Unit Weight, UW (g/cm^3) and Marshall Stability/Flow ratio, S/F (kN/mm). A specific nomenclature was used to describe the mixtures; first a capital letter to indicate the type of filler: Cement (C) and Lime (L), secondly a number referring to the % of RA (0, 20, 40, and 60%). Thus, for example C-20 indicates a mixture that uses cement as filler and contains 20% RA.

Wheel tracking

The Wheel tracking test (NLT-173 standard) [14] was carried out to evaluate the resistance to permanent deformation. Three prismatic specimens were placed inside a climatic chamber at a temperature of 60 ºC and subjected to the alternating passage of a wheel for over 120 minutes (Figure 3). The permanent deformation rate (PD rate) was the average deformation velocity of the three specimens at the interval between 105 and 120 minutes from the start in a deformation versus time graph. According to Spanish PG-3, this rate must be lower than 20 μm/min.

Immersion-compression

The Immersion- compression test (NLT-162 standard) [15] was carried out to evaluate the effect of water on compressive strength. Ten cylindrical samples of 101.6 mm in diameter and 101.6 mm in height were made with the Marshall optimum asphalt content. Five samples were immersed in water at 60ºC for 24 hours and the other five were kept at 20ºC without being submerged in water. The average compressive strength in each group was determined. Stripping was evaluated on the basis of the retained strength ratio RSR (%):

$$\mathrm{RSR} = \frac{\mathrm{CS_W}}{\mathrm{CS_D}} \times 100 \qquad [1]$$

Where CS_w = average wet compressive strength (MPa), CS_D = average dry compressive strength (MPa). According to Spanish PG-3, this ratio must be higher than 75%.

3. Results

3.1. Marshall parameters

Table 3 shows the results of the Marshall Parameters and optimum asphalt contents (B_o). Also given are the Bulk Specific Gravities of Aggregates (G_{sb}) in paraffin oil used in the mix designs (paraffin oil was used because of its absorption, which is very similar to asphalt absorption). According to these results, compliance with the Spanish PG-3 for HMA as a base course material in low volume roads having heavy traffic category T3 is achieved. Traffic category T3 refers to the following interval of Annual Average Daily Heavy Traffic: $50 \leq AADT_H < 200$.

It can be seen in Table 3 that the specific gravity (Gsb) of the aggregates diminishes as the coarse RA % increases. This is due to the mortar cement attached to the coarse RA; the higher the amount of attached mortar, the lower the specific gravity will be [12]. This translates to a lower unit weight (UW) of the mixtures and produces an increase in the voids in the mineral aggregate (VMA). Therefore, to obtain the PG3 specified air voids content (Va) it is necessary to increase the binder content. Figures 4 and 5 represent the curves of the Marshall parameters. These curves clearly show that the densities of the mixtures drop sharply as the coarse RA they contain increases.

On the other hand, the stability and deformation curves do not follow such a clearly defined pattern. In this way, in figure 4 it can be seen that by using cement filler, both the stability and deformation values of the mixtures follow this order (from lowest to highest): C-40; C-20; C-0 and C-60. However, figure 5 shows the following stability order (from lowest to highest) when lime is used as a filler: L-60; L-40; L-20 and L-0; while the deformation order is: L-0; L-20; L-40 and L-60. Therefore, when using lime, the increase in coarse RA% causes stability to diminish and deformation to increase.

Figure 6 presents the curves corresponding to the Marshall stability/flow ratio (S/F). The Marshall S/F ratio may be used to measure stiffness so that the mixtures with high values will have a greater resistance to permanent deformation. In figure 6, this ratio can be seen to diminish as RA% increases. This behaviour is much more clearly defined when lime is used (Figure 6a). However with the cement filler, although the trend is the same, the ratio curves are superimposed over one another (Figure 6b). In addition, it is possible to see that in the mixes using cement filler, the Marshall ratios are higher. This indicates that the mixes made with cement filler are stiffer than those using lime filler. This may be attributed to the fact that lime absorbs a large amount of moisture or there may even be a possible chemical reaction between the lime and the mortar or with some of the components of the RA, which may be detrimental to the mechanical behaviour of the mixes.

3.2 Permanent deformation

The PD rates recorded for the mixtures are shown in Table 3. All the values are below the limit of 20 μm/min. All the mixtures present good resistance to permanent deformation. The differences are not very high. A two-way ANOVA analysis was carried out to test the significance of these results. The dependent variable used was the PD rate. The two factors were: % of RA (0, 20, and 40%) and Filler type (cement, lime). From a statistical point of view, the results showed that the % of RA ($p=0.443$) and Filler type ($p=0.876$) were not significant for a 95% confidence interval. Therefore, from a statistical point of view, the differences in the results of the PD rates between mixtures were not significant.

On the other hand, these results were predictable given that mixtures C-0; C-20 and C-40 were designed with very similar air voids (Va) and Stability/Flow ratios (S/F). In mixtures

L-0; L-20 and L-40 the differences were higher; the air voids were similar but not the S/F ratios. In mixtures L-0; L-20 and L-40 the S/F ratios and PD rates decreased as the % of RA increased. Logically, the performance of the mixtures with cement is better because they are stiffeners.

3.3. Stripping behaviour

Table 3 shows the results of the compressive strength tests carried out on the HMA samples in the dry and wet state, as well as their retained strength ratio (RSR):

- The C-0 mixture that used cement as a filler and did not use coarse RA had a retained strength ratio equal to 85%, exceeding the 75% threshold specified by PG-3. Mixtures C-20; C-40 and C-60, presented values of 59%, 54% and 63% respectively, and the 75% threshold was not reached.
- The L-0 mixture that used lime as filler and did not contain coarse RA resulted in an unexpected RSR of 69%. Mixtures L-20, L-40 and L-60 had RSR values of 79%, 51% and 53% respectively. Therefore, with the exception of mixture L-20, mixtures using 3.75% of NA filler plus 1.00% lime filler did not reach the 75% threshold either.

A two-way ANOVA analysis was carried out to test the significance of these results. The two factors were: % of RA (0, 20, 40 and 60%) and Filler type (cement, lime). The results of this analysis showed that the % of RA ($p=0.299$) and Filler type ($p=0.794$) were not significant for a 95% confidence interval. Therefore, from a statistical point of view, the differences in the values of the RSR between mixtures were not significant. Nevertheless, the effect of RA % proved to be of greater importance, as it explained 65.44% of the total variance, while the effect of the Filler type only explained 0.91%.

Moreover, a close look at the results presented in Table 3 reveals that the strengths of the samples of mixture C-0 were lower than those of the samples of mixture L-0, which agrees with the results of the S/F Marshall ratio in Table 3. However, in mixtures containing coarse RA, the samples with cement filler added were stronger than those made with lime filler. This is in keeping with the results of the S/F Marshall ratio of the samples made with cement filler. In addition, when cement filler was used, all of the strength values of the samples made with RA were higher than those corresponding to mixture C-0. This was not, however, the case when the lime filler was used. While the strength of the samples in the dry state increased in mixtures L-40 and L-60, it diminished in mixture L-20. With the lime filler, the strengths of the samples in the wet state remained very similar.

It is very important to emphasize that these mixtures may cause durability problems, since the RSR values are clearly insufficient. Some of the reasons for these poor values may be the following:

- Coarse RA contains some cement mortar particles and impurities that may crumble and break during the compaction process owing to impacts received by the samples.
- The high absorption of asphalt reduces the % of effective asphalt covering these aggregates. This results in mixtures that are lacking in asphalt.
- The high absorption of water causes easy breakage of the cement mortar that is attached to the coarse RA.

4. General discussion

This research confirms some of results reported by other studies [1-5] and proves that the VMA in HMA increase with the incorporation of coarse RA. It also proves that HMA designed with coarse RA presents enough permanent deformation and stiffens properties. Nevertheless, the retained strength post water immersion diminishes with the incorporation of coarse RA. Other studies [6-8] have encountered the same problem which they attribute to the high water absorption rate of RA. This property encourages bitumen displacement by the water, giving rise to the stripping of the aggregates and a generalised loss of mechanical properties. It is the cement mortar adhered to the coarse RA, together with some impurities, which confer this high water absorption on the material. Finally, more extensive research is needed to study the durability behaviour of HMA made with coarse RA from C&D waste.

5. Conclusions

On the basis of the results of this research work the following conclusions can be drawn:

- HMA materials designed with coarse RA meet the Marshall parameters for low volume roads and present a good resistance to permanent deformation.
- HMA materials designed with coarse RA present poor stripping behaviour which has a negative effect on the durability of the mixtures. If this problem were solved, they would be apt for use in pavements for low volume roads.
- HMA materials designed with coarse RA have a quality deficit that needs to be technically and economically quantified. The HMA with coarse RA will be feasible in low volume road pavements only if they are of similar quality to HMA with NA.
- Consequently further research is needed to ensure the technical and economical viability of asphalt mixtures incorporating coarse RA. A few guidelines for this future research are given below:
  - It is advisable to repeat the entire process of mix design, but this time eliminating impurities and plaster fragments that may have remained in the RA during the fabrication process at the plant. This would lead to a substantial improvement in the quality of the RA.
  - It is advisable to give the mixture time to stand at a high temperature before being compacted. This would allow enough time for the absorption of the binder by the cement mortar and, as a result, a higher binder content would be obtained than what is obtained without standing time to facilitate absorption.

- The utilization of antistripping agents in bitumen, and pre-treatments of RA should be included in further investigations to improve the durability of the mixtures made with coarse RA.

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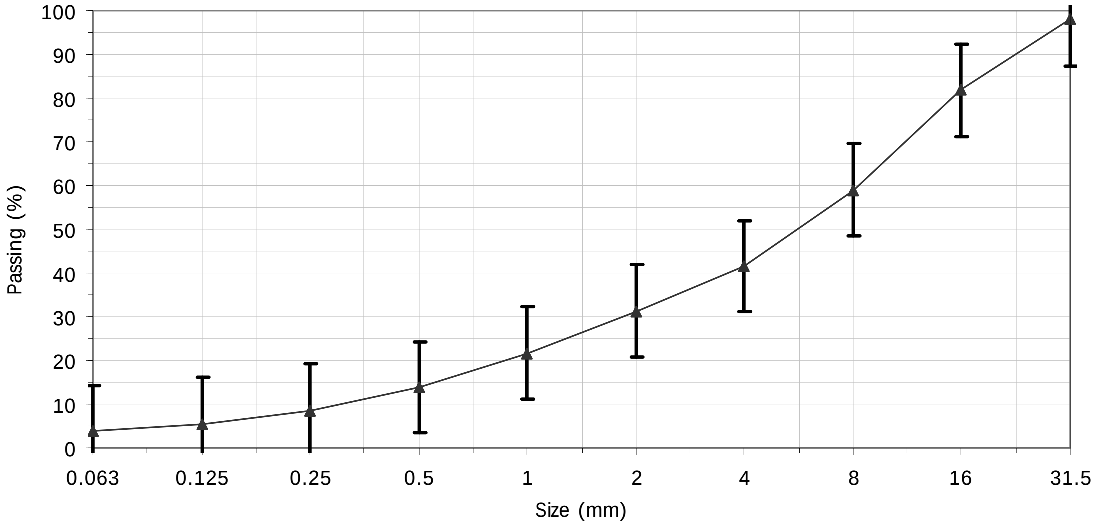


Standard error bars represent the 99% confidence interval of a mean

Figure 1. Grading curve of recycled aggregate

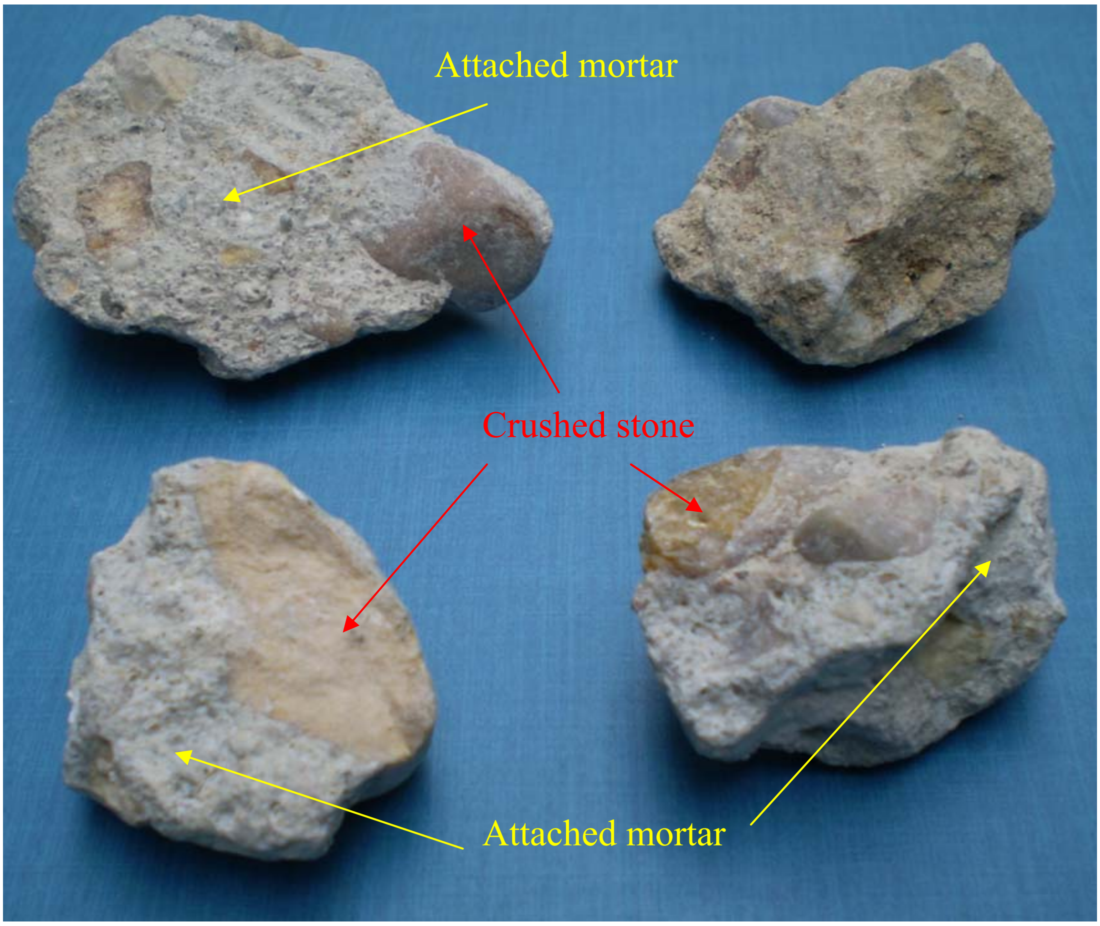


Figure 2. Coarse aggregates recycled from C&D waste

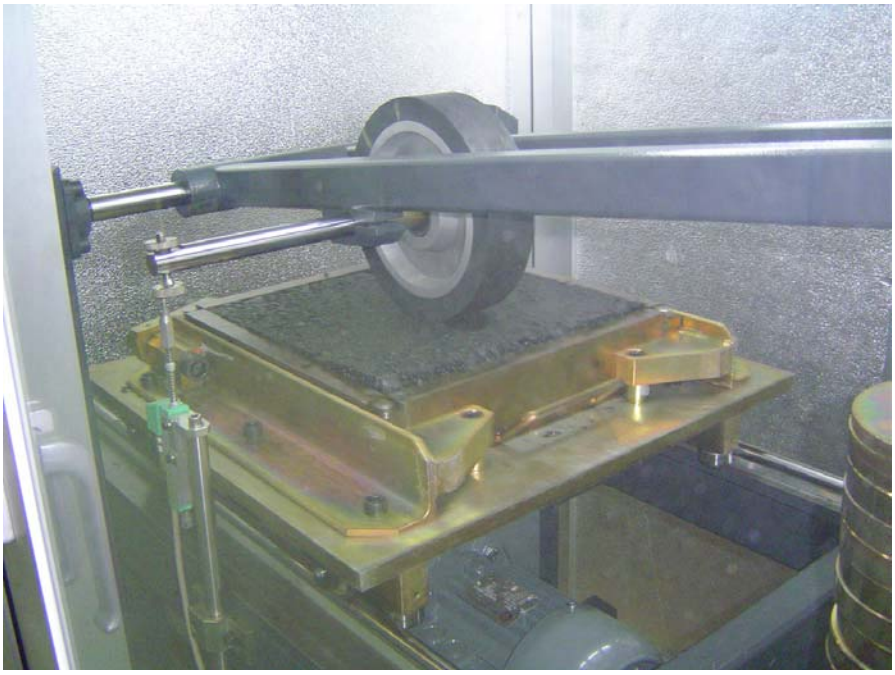
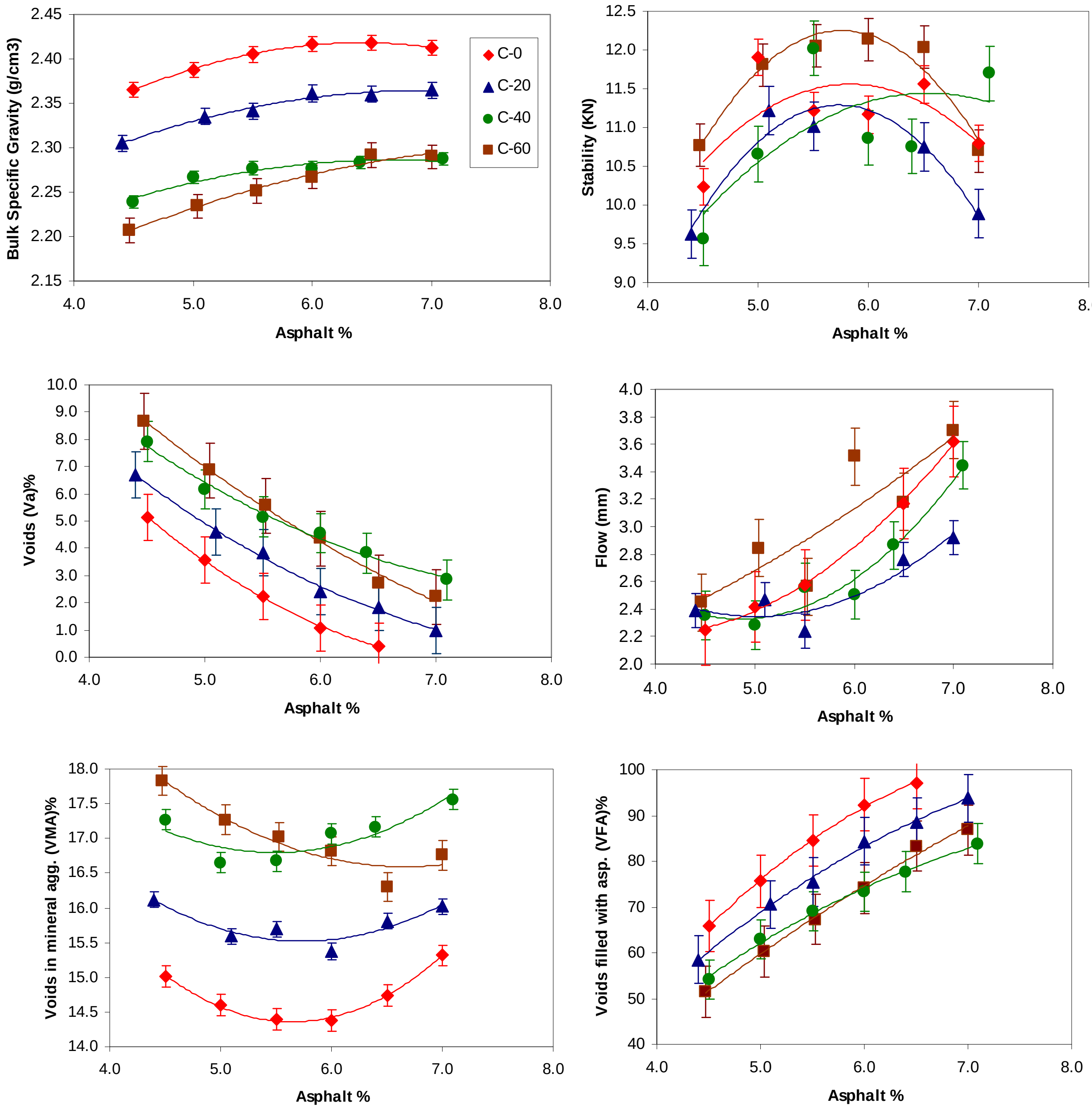


Figure 3. Wheel tracking test



Standard error bars represent the 99% confidence interval of a mean

Figure 4. Marshall Curves, cement filler

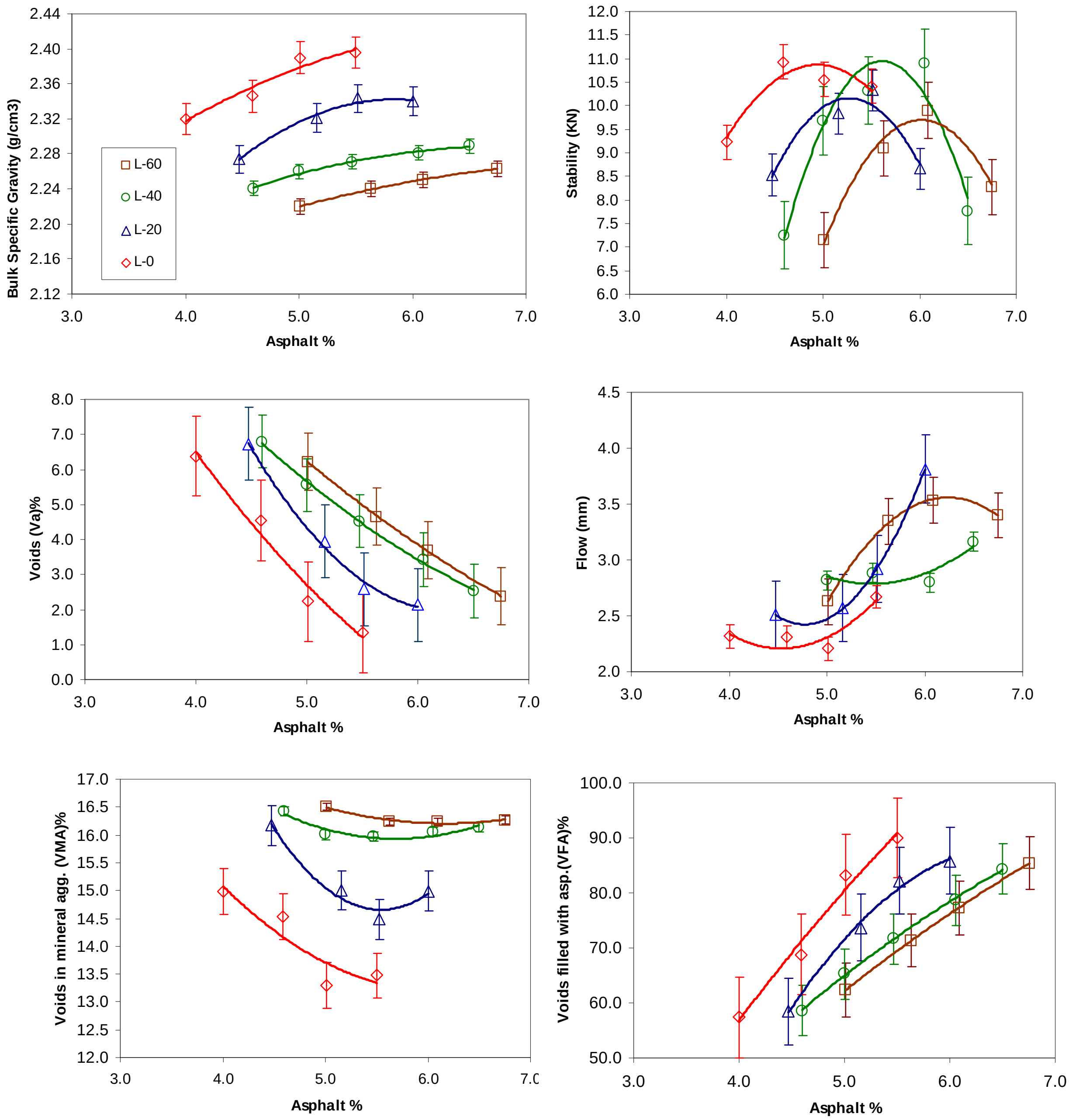


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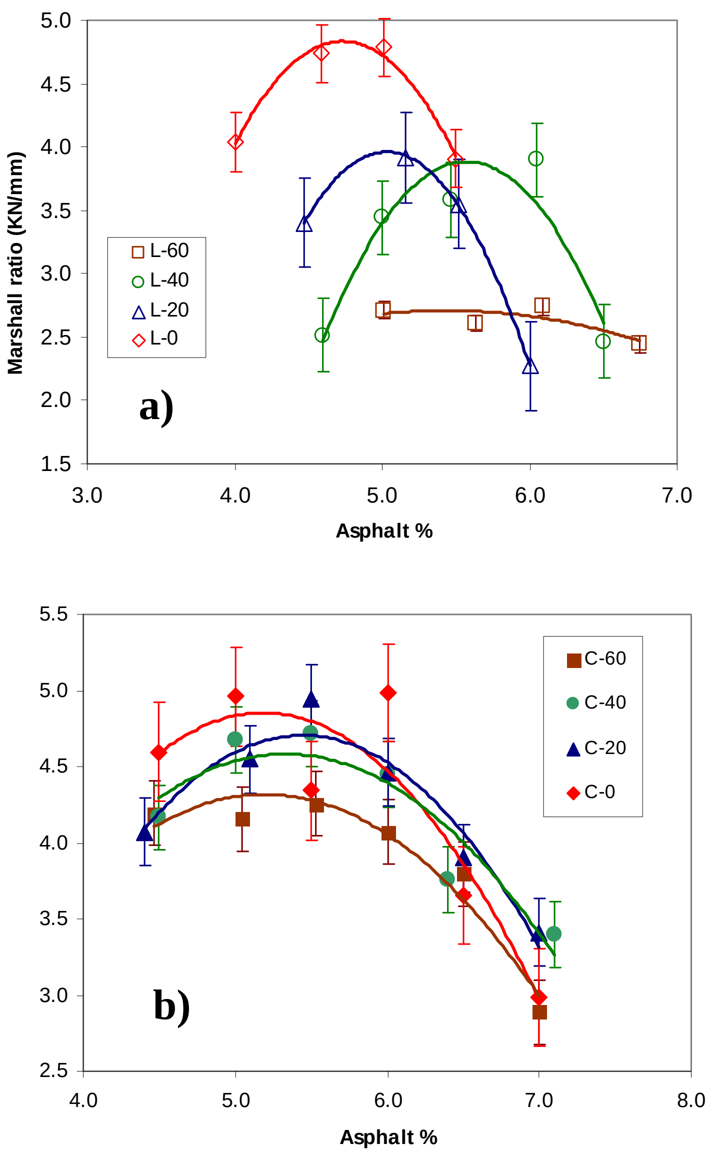
Figure 5. Marshall Curves, lime + natural filler



Standard error bars represent the 99% confidence interval of a mean

Figure 6. Marshall stability-flow ratio. a) lime filler, b)cement filler

Test	PG-3 Requirements	NA			RA (0/40)
		0/6	6/12	12/25	
Flakiness index (%)	<35	--	17.2	19.4	34
Fractured particles (%)	100	100	100	100	100
Sand equivalent (%)	>50	85	--	--	67
LA fragmentation (%)	<30	--	--	22.1	34
Bulk Specific Gravity	---	2.76	2.69	2.68	2.63
Water absorption (%)	--	--	0.21	0.12	6.1

Table 1. Characteristics of the aggregates

Sieve sizes UNE-EN-933-2 (mm.)									
Coarse aggregate (RA)					Fine aggregate (NA)				Filler
25	20	12.5	8	4	2	0.50	0.25	0.125	0.063
100	95	75	60	37.75	28.5	13	10	7	4.75

Table 2. Grading curve of hot asphalt mixtures

Mixture	Marshall Parameters									PD rate (µm/min.)	Strength (MPa)		RSR (%)
	G_{sb}	B_o (%)	VMA (%)	Va (%)	VFA (%)	F (mm)	S (kN)	S/F (kN/mm)	UW (g/cm^3)		wet	dry	
C-0	2.661	4.5	15.0	5.0	66.8	2.3	10.5	4.6	2.36	12.97	1.2965	1.5243	85
C-20	2.634	5.0	15.5	5.0	69.6	2.4	10.8	4.5	2.33	14.08	1.4787	2.5198	59
C-40	2.592	5.5	17.0	5.0	69.1	2.4	11.0	4.6	2.27	13.26	1.6926	3.1456	54
C-60	2.571	5.5	17.0	5.5	67.0	2.9	12.2	4.2	2.26	----	1.7216	2.7296	63
L-0	2.625	4.3	14.3	5.0	65.1	2.2	10.3	4.7	2.34	11.32	1.3105	1.8930	69
L-20	2.597	4.7	15.5	5.5	67.1	2.4	9.8	4.1	2.30	13.15	1.3175	1.6755	79
L-40	2.562	5.0	16.2	5.6	66.1	2.8	10.0	3.6	2.25	16.25	1.3891	2.7440	51
L-60	2.532	5.5	16.4	5.0	70.0	3.2	9.0	2.8	2.24	----	1.2684	2.3968	53
PG-3 limit values	-----	Min. 3.5	≥14	5-9	-----	-----	-----	----	----	≤20	----	----	≥75

Table 3. Mechanical test results