Laboratory study on Asphalt Concrete with polypropylene plastic and non-selected construction and demolition waste

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Abstract. A contribution for solving the depletion problem of natural resources and, simultaneously, the abundance of urban and industrial wastes, could be its application in pavement construction. For this purpose, a laboratory study is carried out in which Non-Selected Construction and Demolition Waste (NS CDW) and polypropylene (PP) plastic waste are incorporated in hot bituminous mixtures as potential replacements, respectively, for natural aggregates and bitumen. Four AC20 50/70 mixtures were put to test: a control mixture exclusively with natural aggregate; a mixture in which 10% of the mass of natural aggregate is replaced by NS CDW; a mixture in which 6% of the mass of bitumen is replaced by PP waste and a mixture in which are combined the replacement of 10% of the mass of natural aggregate by NS CDW and 6% of the mass of bitumen is replaced by PP waste. Results show that: i. a slight decrease in the Marshall stability and rise in the Optimal Bitumen Content in the mixture with 10% of NS CDW compared to the Control mixture; ii. adding PP to the mixture containing NS CDW retrieves the result for the optimum binder content obtained for the Control mixture. Both wastes diminish mixtures´ resistance to moisture.

Keywords: AC 20, Construction and Demolition Waste, Polypropylene waste, Marshall test, Sustainability

1 Introduction

Extracting and processing natural aggregates (NA) for bituminous mixtures have significant negative impacts, both economic and environmental. Considering the need for its high amounts, they require the expansion or creation of new quarries, but also its haul, which lead to high energy consumption and emission of greenhouse gases [1][2]. A way to minimize these harmful effects could be the replacement of NA, in whole or in part, with wastes. Table 1 presents the total production of HMA and WMA in some EU countries and Table 2 the amount of different wastes generated each year in Portugal.

Table 1. Amount of HMA and WMA produced in some European countries in 2022 [3]

Portugal	Spain	France	Italy	GB	Germany	EU-27
3.1 Mt	17.1 Mt	30.7 Mt	37.6 Mt	24.2 Mt	39.0 Mt	212.5 Mt

Table 2**.** Average quantity of different wastes produced each year in Portugal

Type of waste	Quantity	Year	Reference
CDW	2 Mt/year	2018	[4]
Plastics	415 Kt/year	2018	[5]
Steel slag	270 Kt/year	2005	[6]
Crushed tires	84 Kt/year	2018	[7]

Selected Construction and Demolition Waste is often traded in different varieties, such as, Recycled Concrete Aggregates (RCA) [8], brick masonry aggregates with or without mortar [9], ceramic aggregates [10] or recycled bituminous mixes (RAs) [11]. These selected materials offer higher quality and constancy in their characteristics compared to NS CDW, whose variety of constituents have negative consequences on the geometric, physical and chemical characteristics of the compound aggregate and eventually on the volumetric and mechanical response of the bituminous layers. Characteristics like lower mechanical resistance of granular elements made of brick and ceramic, result in poorer grading, lower angularity or smother surfaces. On the other hand, higher porosity of mortar and ceramic provide greater absorption of water and bitumen. Simultaneously, those smoother faces of brick fragments, often covered with fine material, and the presence of elements with higher acidity affect negatively the affinity with the binder [12][13]. However, and because of these defects, researchers have been testing strategies to improve the behavior of the bituminous mixtures composed by a percentage of NS CDW. Those strategies can be the identification and removal of undesirable constituents [14], the granulometric selection of particles [15] and surface treatments such as strengthening or removing mortar surfaces adhered to the recycled aggregate [13].

2 Objectives and scope

The objective of this study is to learn some of the effects on an AC 20 mixture for base course with the incorporation by dry method of partial replacement of natural aggregate by NS CDW and bitumen by PP.

3 Materials

3.1 Natural Aggregate and Non-selected Construction and demolition waste

For the production of hot bituminous mixtures, different fraction of NA and a NS-CDW (Figure 1) were used. NA is a fully crushed stone from a granitic quarry. To characterize NS CDW, the identification of the relative proportions of the constituent materials was conducted (Table 3), according to EN 933-11 [16]. Figure 2 shows the particle size

distribution of all NA fractions and NS CDW. As can be seen, NS CDW is a poorly graded material, with high presence of fine particles (percent passing in sieve 0.063 mm), mostly resulting from the presence of brick particles (R_b), shown in Figure 1. Results of other geometrical and physical tests are shown in Table 4. Properties` results mentioned in this table indicate that NA comply with all specifications of CE-EP [17], but NS CDW exceeds the Water Absorption and the LA coefficient limits. However, this situation may not be a problem as only 10% of NS CDW will be considered and not a total replacement of NA, so the combination of NA and 10% of NS CDW fulfils the requirements.



Figure 1. Sample of NS CDW

Table 3. Constituents of NS CDW according to EN 933-11 [16]

Constituents	R_c	R_u	R_b	R_a	R_g	R_s	X	FL
%	34	29	25	0.2	0.2	8	3	0.3

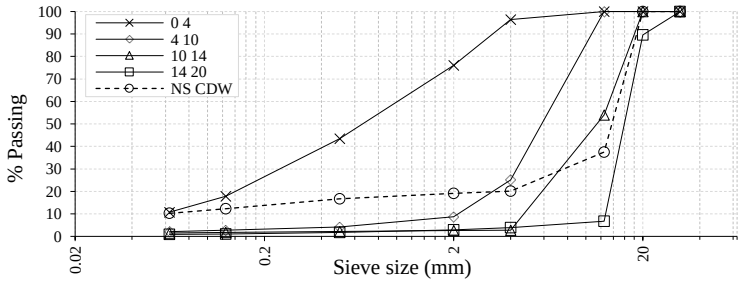


Figure 2. Gradings results according to EN 933-1 [18]

Table 4. Physical and geometrical characteristics of NA and NS CDW

	Standard	0/4	4/10	10/14	14/20	NS CDW	CE-EP (2014)
FI	EN 933-3 [19]	-	26	15	9	28	30
MB_F	EN 933- 9 [20]	-	-	-	-	6.7	10
LA	EN 1097-2 [21]	-	37	32	-	55	40
ρ_a	EN 1097-6 [22]	2.66	2.67	2.67	2.67	2.4	TBD
ρ_{rd}	EN 1097-6 [22]	2.65	2.61	2.62	2.63	2.17	TBD
ρ_{ssd}	EN 1097-6 [22]	2.65	2.63	2.64	2.64	2.1	TBD
WA_{24}	EN 1097-6 [22]	0.1	0.8	0.7	0.6	6.7	2

TBD (To be declared)

3.2 Bitumen, filler and polypropylene waste

This study was performed using a 50/70 penetration class bitumen, with penetration value of 57 × 0.1 mm (at 25 °C, 100 g and 5 s), according to NP EN 1426 [23] and a softening point of 49.8 °C, according to NP EN 1427 [24]. Limestone powder was used as filler and whose Blaine surface area is 5400 cm^2/g and specific gravity is 2.7 g/cm^3. Polypropylene plastic waste (Figure 3a) has a melting point between 130-171 °C and specific weight between 0.855 - 0.946 g/cm^3. After heating at 150 °C, the appearance is as shown in Figure 3b, which indicates adherence ability at the required mixing temperature according to EN 12697-35 [25].



a) b)

Figure 3. Polypropylene waste: a) dry sample, b) after being heated at 150 ℃

4 Preparation of Asphalt Concrete and formulation method

Four different compositions were produced: i. a control mixture containing only natural aggregate; ii. a mixture in which 10% of NA was replaced by NS CDW; iii. a mixture in which 6% of bitumen was replaced by PP waste; iv. a mixture containing both, 10% of NS CDW replacing NA and 6% of PP waste replacing bitumen. These mixtures are labeled as Control mixture, 10 CDW, 0 CDW 6PP and 10 CDW 6PP respectively and their gradings are presented in Figure 4. Waste materials are incorporated through the dry method [26]. For each composition, five series (one per binder content) of four cylindrical Marshall specimens were compacted according to EN 12697-30 [27], applying 75 blows in each side.

The AC20 base 50/70 formulation was conducted following the Marshall method, as recommended by National Annex included in the Portuguese version of EN 13108-1 standard [28]. The Optimum Binder Content obtained in each composition is the mean value between: i. the bitumen content corresponding to maximum Marshall stability, ii. the bitumen content corresponding to the maximum bulk density, and iii. the bitumen content corresponding to the average of the required limits of air voids. In the mixture under study (AC 20) the air voids target is 4.5% [17].

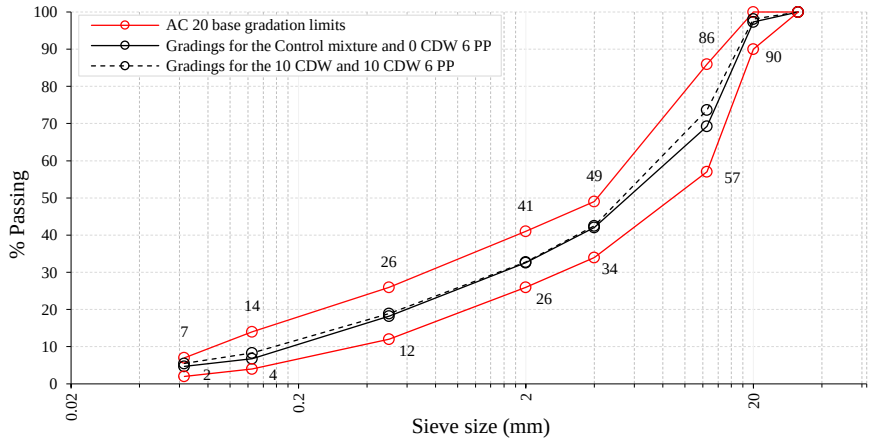


Figure 4. Gradings for the control mixture and for the mixtures containing wastes

5 Results and discussion

Stability results shown on Figure 6a indicate that the mixture 10 NS CDW presents a slight reduction compared to the obtained for the control mixture. However, the inclusion of PP increases the stability dramatically. Maximum stability with less binder content enables savings concerning the optimum binder content as will be shown in Table 5. Stability results yet indicate the non-compliance for base course according to the Portuguese specifications [17], especially those containing PP. Differences in flow (Figure 6b) are less clear, yet PP appears to have a flow reducer effect for moderate bitumen contents (4.5%, 5.0% and 5.5%). Similar observation is made for the Marshall quotient (Figure 6c) where for moderate bitumen contents, PP might bring benefits in respect to permanent deformation resistance.

A plausible cause for the increase in Marshall stability and Marshall quotient in the 0 CDW 6PP and 10 CDW 6PP compositions are the mixture agglomerations containing PP which are shown in Figure 6. During preparation for the maximum density test [29] these agglomerations appeared to be extremely difficult to get loose and be separated manually and thus, can give mixtures a greater resistance.



Figure 5. Agglomerates of bituminous mixture containing polypropylene

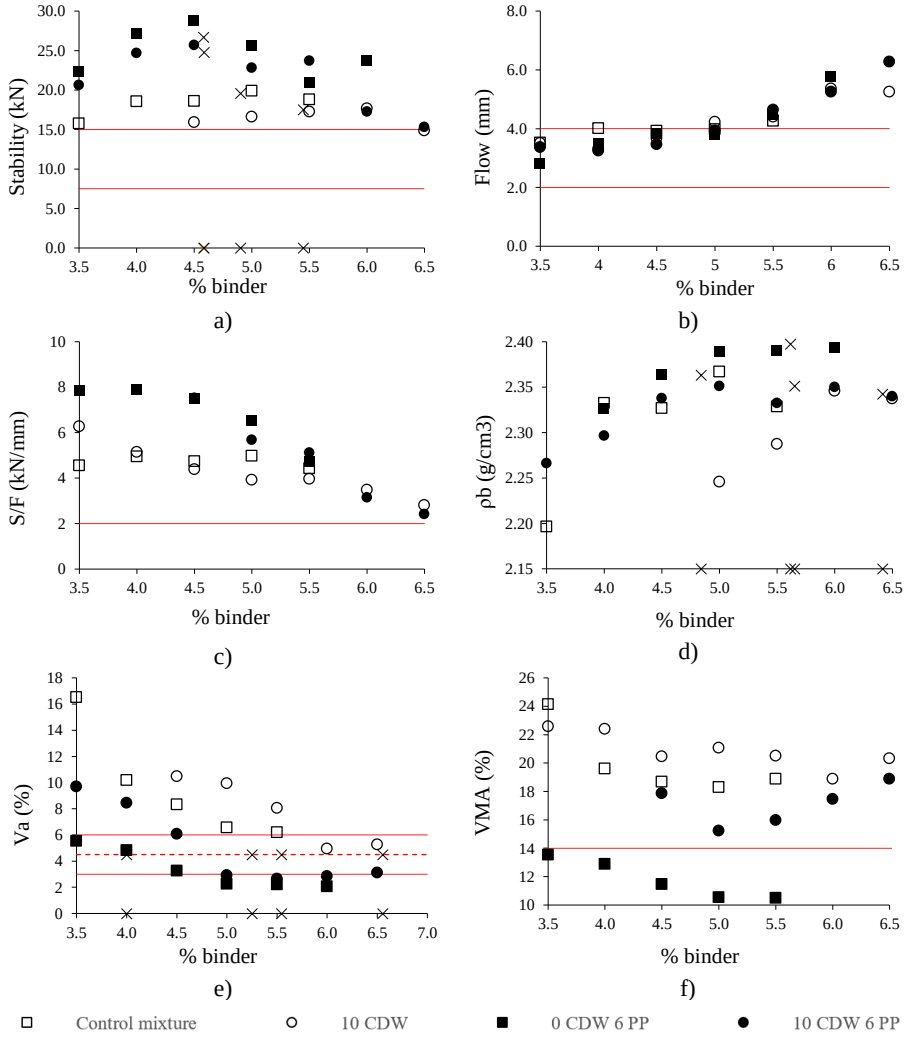


Figure 6. Results: a) Stability, b) Flow, c) Marshall Quotient, d) Bulk density, e) Voids, f) VMA. Red lines represent the Portuguese requirements according to CE-EP regarding AC 20 base [17].

Addition of NS CDW and PP waste have also visible impacts on the volumetric characteristics (bulk density, air voids and VMA-Voids in Mineral Aggregate). Higher porosity of NS CDW decreases specimens´ bulk density (Figure 6d). Cement mortars and brick particles contribute to this decrease as they are lighter than the natural aggregate. Maximum bulk density in 10 CDW is reached at 6.42% bitumen content while for the control mixture is reached with 4.84% bitumen. The effect on the Optimum Bitumen Content with the addition of PP respecting bulk density is the fact that on both, 0CDW 6PP and 10CDW 6PP, the maximum bulk density is leveled, reaching similar

binder content (≈5.6%). As NS CDW particles have greater porosity than natural aggregate, the volume of air voids in mixtures where NS CDW is incorporated will increase (Figure 6e). As expected, increments in bitumen content diminish volume of voids in all mixtures as these are being filled by bitumen. However, this decrease is smoother in mixtures with NS CDW because the bitumen is absorbed, mainly by the adhered mortars in brick and concrete particles (R_c). The target air voids (4.5%) is obtained with fewer binder in mixtures containing PP waste. VMA is higher in the mixture with 10 % of NS CDW, also a consequence of the porosity of the NS CDW (Figure 6f). Likewise, PP waste which also reduces significantly VMA, in particular 0 CDW 6 PP.

Results for the Optimum Binder Content are presented in Table 5 next to the binder content which enables maximum stability (S_{max}), maximum bulk density (ρb_{max}), and 4,5% air voids ($Va_{4.5}$). For the Control mixture, OBC is 5.1% while for the 10 CDW is 6.1%, 1% more than in the control mixture. The replacement of 10% of NA by NS CDW reduces some of the bituminous mixture properties and thus demands more binder. However, partial substitution of bitumen by plastic can refrain this growth by increasing stability and density with less binder content. Table 5 illustrates the influence of each parameter on the OBC. It is notorious the effect of volumetric properties on the increase of binder content, especially regarding 10 CDW and 10 CDW 6PP mixtures.

Table 5. Determination of the Optimum Binder Content (%)

	% bin - S_{max}	% bin - ρb_{max}	% bin - $Va_{4.5}$	OBC (%)
Control mixture	4.90	4.84	5.55	5.1
0 CDW 6 PP	4.58	5.61	4.00	4.7
10 CDW	5.45	6.42	6.56	6.1
10 CDW 6PP	4.59	5.65	5.26	5.2

6 Moisture damage resistance

Moisture damage resistance of a bituminous mixture is a measure of its durability. For this study, the Index of Retained Stability (IRS) is determined according to US military standard MIL-STD–620A [30], in which two groups of three specimens are immersed, for different periods of time, in a water bath at 60 °C. The magnitude of stability reduction caused by water contact is determined using Eq. (1). Where S_1 is the mean stability for the group immersed during a period between 35 and 40 minutes and S_2 is mean stability for the group immersed during 24h. Results for the four mixes produced with the Optimum Binder Content are shown in Figure 7. It can be observed that both wastes have a negative impact towards moisture damage resistance. However, minimum requirement for AC 20 base (80%) [17] is hardly achieved for 10 CDW 6 PP.

$$IRS_{Marshall} = \frac{S_2}{S_1} \times 100\ (\%) \quad (1)$$

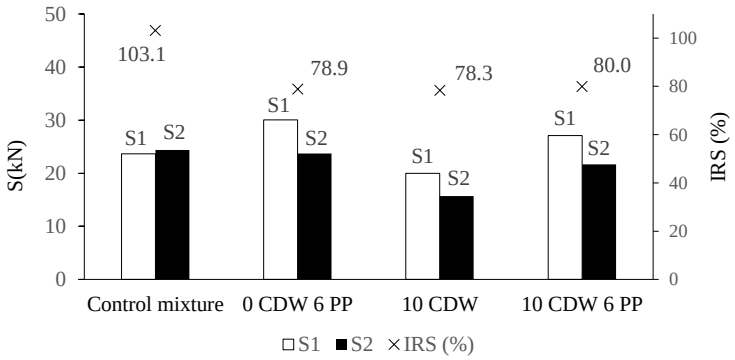


Figure 7. Moisture damage resistance

7 Conclusion and future work

This study is focused on the Marshall and volumetric properties and also moisture damage resistance of mixtures with wastes. Results indicate that the replacement of 10% of NA by NS CDW reduces some properties of the Asphalt Concrete and demands a higher value of bitumen content. They also suggest that the combination with PP can have a fruitful effect concerning bitumen savings. On the contrary, moisture resistance is negatively affected with the incorporation of both wastes and for this reason, a slight reduction of NS CDW and PP percentages should be considered in the near future.

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