May recycled concrete be used as an alternative material for asphalt mixtures?

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ABSTRACT: Recycling of materials is a growing need nowadays, to ensure the sustainable development of the Society (i.e., reducing the use of natural resources and preventing of wastes). In this context, some residues obtained from construction and demolition works are likely to be utilized in new products. Therefore, this work aims at investigating the properties of recycled concrete, as one of the principal construction waste materials, to study the feasibility of its use (added value) as part of the aggregates to be used in asphalt mixtures for road pavements. Laboratory tests were performed to characterize and compare the recycled concrete to natural granite. Then, the influence of using 30% waste material in asphalt mixture was assessed through water sensitivity tests. As a conclusion, the use of recycled concrete as an alternative aggregate for asphalt mixtures is viable, but its application should be prudent due to its high water absorption and low wear resistance.

1 INTRODUCTION

In Portugal, some natural resources used in the construction sector, such as aggregates, are relatively abundant and cheap, leaving behind schedule the management of construction and demolition waste (CDW). However, preventive measures are urgent to be taken to increase sustainability in this activity because sooner or later these natural resources will become scarce.

In this context, the conceptual basis of this work is trying to change the current linear economy paradigm into the new EU Circular Economy Strategy (European Commission, 2015), also transposed to the Portuguese Circular Economy Action Plan (Presidência do Conselho de Ministros, 2017), and in particular, with its fifth action focused on developing a new life for wastes. The main objectives of that action are increasing the introduction of secondary raw materials into the economy, reducing the production of waste and promoting the reduction of the extraction of natural resources.

In particular, this work aims at investigating the properties of recycled concrete, which is one of the most significant CDW materials in Portugal (Coelho and Brito, 2010), to study the feasibility of its use in new asphalt mixtures for road pavements. According to Hendriks et al. (2004), concrete is generally the largest share of CDW materials in several countries (usually around 40%). The properties of the recycled concrete were evaluated through a series of tests in the lab to analyze if this material complies with the specifications related to aggregates for road paving works (Estradas de Portugal, 2014). Then, an asphalt mixture with 30% recycled concrete was produced to evaluate its durability (assessed by indirect tensile strength and water sensitivity tests) against a conventional asphalt mixture. The application of this waste on urban roads has a remarkable interest in the scope of cities circularity concept, by reducing the burdens associated with the transportation stage.

In 2008, construction was the economic sector responsible for the production of the most substantial amount of waste produced in the EU (Schrör, 2011), which amounted to 33% of the total. In the European Community, there has been a growing concern with waste generated by the construction industry. In 2010, only about 30% of the building materials were recycled as raw materials, a number that could rise to 90%, helping to support sustainable construction and generating a series of environmental and economic benefits (Sonigo et al., 2010).

More recent data presented by Eurostat (2019) showed that five tons of waste were generated per EU inhabitant in 2016, from which 46% were landfilled and only 38% were recycled. In 2016, the total waste generated in the EU-28 by all economic activities and households amounted to 2 533 million tons, which was the highest amount recorded during the period 2004-2016. The share of different economic activities and households in total waste generation in 2016, also presented by Eurostat (2019), assigned 36% of the generated waste to the construction area, which remains the economic activity with higher waste generation in EU. These numbers demonstrate the relevance of the work presented in this paper.

However, one of the common hurdles to recycling and reusing CDW in the EU is the lack of confidence in the quality of CDW recycled materials. There is also uncertainty about the potential health risk for workers using those materials. This lack of confidence reduces and restricts the demand for CDW recycled materials, which inhibits the development of CDW waste management and recycling infrastructures in the EU. Thus, the European Commission (2016) published a protocol aiming to increase confidence in the CDW management process and trust in the quality of CDW recycled materials, namely by defining methods to improve waste identification, source separation, and collection, as well as waste logistics and processing, quality management and appropriate policy and framework conditions.

From an economic point of view, the construction and demolition waste recycling worthwhile when the recycled product is competitive in comparison with natural resources in terms of cost and quality. Thus, recycled materials will be more competitive in regions with scarce raw materials, as they can reduce the transportation cost (Tam and Tam, 2006).

One example of previous research on the use of recycled aggregates in road construction was carried out in Nottingham in terms of mechanical and environmental performance (Hill et al., 2001). The authors concluded that recycled aggregates presented a high resistance and that its use could reduce the thickness of the pavement layers. Moreover, they did not give rise to environmental risks when used in asphalt mixtures. Other examples of research in this topic include studies performed in Coruña (Pasandín and Pérez, 2015, Pasandín et al., 2015) to evaluate the incorporation of recycled concrete in asphalt mixtures. In general, these studies concluded that recycled concrete could be an excellent alternative to natural aggregates.

2 MATERIALS AND METHODS

2.1 *Materials*

The CDW material used as aggregate in the present study was recycled concrete. This material was selected after analyzing the most common CDW materials in the waste management and treatment companies in northern Portugal. In this case, the CDW concrete was provided by *Braval*, a company for the recovery and treatment of solid waste, without any treatment after separation. The concrete pieces to be recycled provided were presented in asymmetric blocks with an average length of 15 cm (Figure 1a). The size reduction of the concrete was made in the crushing machine shown in Figure 1b. Figure 1c shows the final result of the material after crushing and ready for the subsequent characterization tests. At this stage, CDW concrete can already be considered as a final recycled product available to be used in asphalt mixtures.

In this study granite was used as natural material or standard aggregate, to make the comparison with the recycled concrete, and for the production of asphalt mixtures. This natural aggregate was selected because it is the most common in northern Portugal, being used for the production of asphalt mixtures. The granite was supplied by *Bezerras* quarry in the commercial fractions of 6/14, 4/6 gravel and 0/4 dust. Besides, limestone filer was used to improve the compatibility with bitumen and the workability of the asphalt mixture. The grading curves of the natural aggregates is shown in Table 1.

A commercial 50/70 bitumen from *Cepsa* was used in this study for the production of asphalt mixtures and determination of the aggregate-binder affinity, which must comply with the characteristics specified in EN 12591.

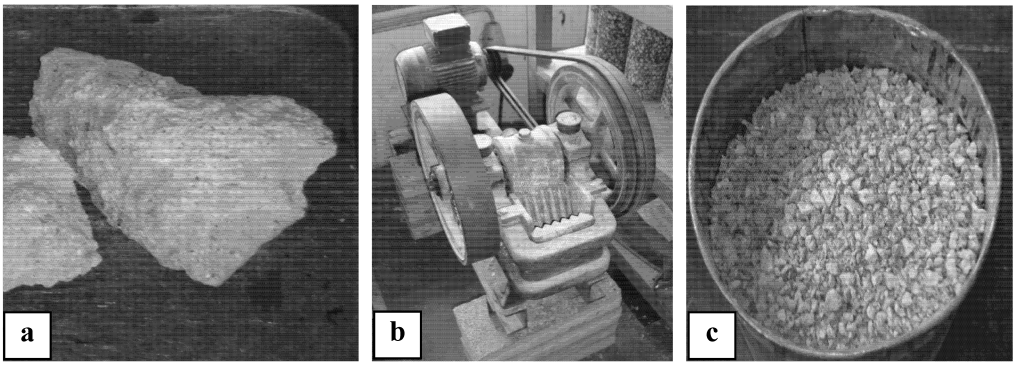

Figure 1. Concrete waste obtained from CDW separation (a), crushing equipment used for CDW treatment (b), and recycled concrete after treatment used in this work (c).

Table 1. Size distribution of the fractions of natural aggregates used to produce the asphalt mixtures.

Sieve dimension (mm)	20.0	14.0	10.0	4.0	2.0	0.5	0.125	0.063
Gravel 6/14	100.0	92.0	40.0	2.0	2.0	1.0	1.0	0.0
Gravel 4/6	100.0	100.0	100.0	10.5	3.9	2.7	1.9	1.3
Dust 0/4	100.0	100.0	100.0	94.0	73.0	39.0	17.0	11.0
Commercial filler	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.0

2.2 *Methods*

Although this work is mainly focused on characterizing the recycled concrete in comparison with the natural granite aggregate, the work began by evaluating the 50/70 pen bitumen used in some parts of the study. The penetration test was performed at 25 °C through EN 1426 standard, and the ring and ball test was performed according to EN 1427 to determine the softening point. The viscosity test was also carried out at various temperatures with the Brookfield rotational viscometer according to EN 13302.

Then, several tests usually applied to characterize aggregates for paving works were carried out on the recycled concrete and the reference granite aggregate. The particle size distribution (grading) was initially evaluated by sieving according to EN 933-1. The shape index (BS 812 Part 105) was also measured since the excess of flaky or elongated aggregates decreases the resistance of the asphalt mixture. The absorption of water (EN 1097-5) is another quite important result because of its direct relation with the bitumen absorption of the aggregates. Then, the affinity between each aggregate and bitumen was assessed under more adverse conditions, according to EN 12697-11. The micro-Deval resistance to wear (EN 1097-1) is another fundamental property measured on coarse aggregates to ensure that a change in the performance of the mixture due to aggregate wear will not occur.

The next phase of the work was the design of the asphalt mixture to be produced with 30% recycled concrete as well as a reference mixture with only natural aggregates. The type of mix selected was an AC 14 surf mixture for road surface layers specified in Portugal by Estradas de Portugal (2014). The bitumen content of the mixture with natural aggregates was obtained by using the Marshall Mix design method, but it was essential to increase the binder content of the mix with recycled concrete to take into account its higher absorption of bitumen. After knowing the difference in water absorption of recycled concrete and natural granite, this value should be multiplied by 30% (CDW content in the mix) and then reduced by 50% to harmonize water and bitumen absorption, based on Lee et al. (1990) work. Finally, the abovementioned asphalt mixtures were produced at 150 °C following EN 12697-35 and then several test samples were compacted in the impact compactor (EN 12697-30) with 75 strokes on each side. After determining their volumetric characteristics (densities and air voids volumes according to EN 12697-5 and EN 12697-6), the specimens were tested by evaluating the indirect tensile strength (EN 12697-23) and the sensitivity to water (EN 12697-12) in order to analyse the influence that the use of recycled concrete has on the durability of the asphalt mixtures.

3 RESULTS AND ANALYSIS

3.1 *Bitumen properties*

The 50/70 pen bitumen used in this work had an average penetration of 52.4 tenths of a millimetre, and a softening point of 52.2 °C. These values are within limits designated in the current specifications for this type of binder (EN 12591).

The viscosity results of the 50/70 pen bitumen at elevated temperatures (production and compaction stage) varied from 6.21 Pa.s at 100 °C to 0.16 Pa.s at 170 °C. The production of asphalt mixtures should occur at the equiviscous (0.3 Pa.s) temperature of around 150 °C.

3.2 *Recycled concrete vs. natural aggregate characteristics*

The recycled concrete has a well-graded size distribution (Table 2). The larger particles of the crushed recycled concrete have a 14 mm dimension, with 96% of material passing on that sieve. The minimum size (less than 10% of passing material) is minimal (0.5 mm), and thus this material corresponds to an aggregate fraction 0/14. The continuous curve of this material is relevant for an excellent fit to the grading curve of the asphalt mixture in the mix design phase.

Table 2. Size distribution of the crushed recycled concrete used in this work.

Sieve dimension (mm)	20.0	14.0	10.0	4.0	2.0	0.5	0.125	0.063
Recycled concrete	100.0	96.0	77.0	32.0	18.0	7.0	2.0	1.0

The shape of the aggregate particles, which should be approximately cubic, was then evaluated, because the use of flaky or elongated particles, which are more brittle, is not desirable. The elongation and flakiness indexes of the recycled concrete (20% and 8%) were nearly equal to the corresponding values of the natural granite aggregate (19% and 7%). The elongation values were higher than the flakiness values, and both materials complied with the 25% limit specified for their use in an AC 14 surf mixture.

The water absorption of recycled concrete (9.8%) was much higher than that of natural granite aggregate (1.2%), either due to the cement used on its composition or its increased porosity. This result can be especially burdensome if asphalt plants are forced to use a more significant amount of energy for drying this aggregate, and also because it is a sign of greater absorption of bitumen, which implies a higher cost of the mixtures (as will be seen in the mix design phase).

The affinity of the aggregates to the bitumen is obtained through visual analysis, so it is essential to present the two aggregates studied before and after the test (Figure 2), namely after being in contact with water to remove part of the bitumen film that covered them. The result of this test corresponds to the surface area covered by bitumen at the end of the experiment, which was only 35% for natural granite and 76% for recycled concrete. As a porous aggregate, recycled concrete needs more bitumen for total wrapping, but has a better affinity with the binder.

The micro-Deval coefficient measures the wear loss of aggregates to be used in road pavements. At the end of the test, it was found that the recycled concrete has a rounded shape, due to its increased wear on the sharp edges. Thus, the wear of recycled concrete (33.8%) was much higher than that of natural granite (3.8%), not meeting the specified limit of 15% for an AC 14 surf mixture. Thus, the use of large quantities of this material in asphalt mixtures should be prudent, preferably in the substitution of fine fractions of aggregate.

Figure 2. Natural granite (left) and recycled concrete (right) before and after binder affinity test.

3.3 *Mix design and evaluation of asphalt mixtures' performance*

After knowing the gradation of all the materials to be used, they were combined to obtain the final grading curves of the asphalt mixtures with natural granite and with 30% recycled concrete. The M1 mixture (only with natural granite) was produced with 46% of 6/14 gravel, 14% of 4/6 gravel, 38% of 0/4 dust and 2% of filler, while the M2 mixture (with 30% recycled concrete) was produced with 30% recycled concrete, 33% of 6/14 gravel, 4% of 4/6 gravel, 31% of 0/4 dust and 2% of filler. Figure 3 shows that the final grading curves of both mixtures (M1 and M2) meet the specified size distribution limits for the AC 14 surf mixture.

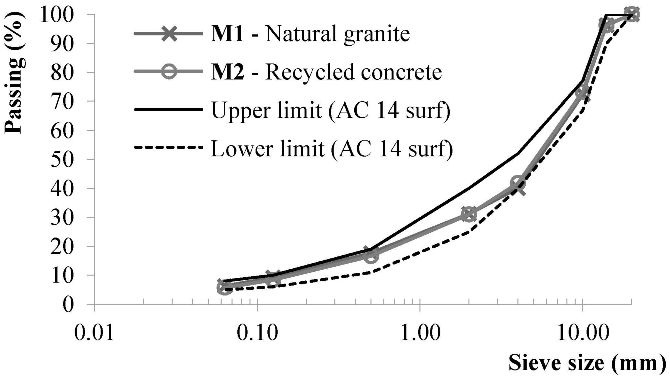

Figure 3. Grading curves of mixtures M1 (natural granite) and M2 (recycled concrete) within the specified limits.

Subsequently, the M1 mixture with natural aggregates was designed with the Marshall Mix design method, and the final binder content obtained in that study was 5.0%. As explained in Section 2, this value was adjusted to the M2 mixture, with 30% recycled concrete, as a function of the increment of bitumen absorption estimated by the variation of water absorption (8.6%) between the two types of aggregates. Thus, it was concluded that the M2 mixture should be produced with a binder content of 6.3%.

After the design of both mixtures, samples were produced to initially determine their volumetric properties (bulk and maximum density, and air voids content). Then, tests were carried out to evaluate the indirect tensile strength (ITS) of the conditioned (wet) and unconditioned (dry) test samples (Figure 4). With those values, it was possible to estimate the water sensitivity (ITSR) of the mixes. These results are presented in Table 3 to assess the relative durability of the control mixture with natural granite (M1) against that with 30% recycled concrete (M2).

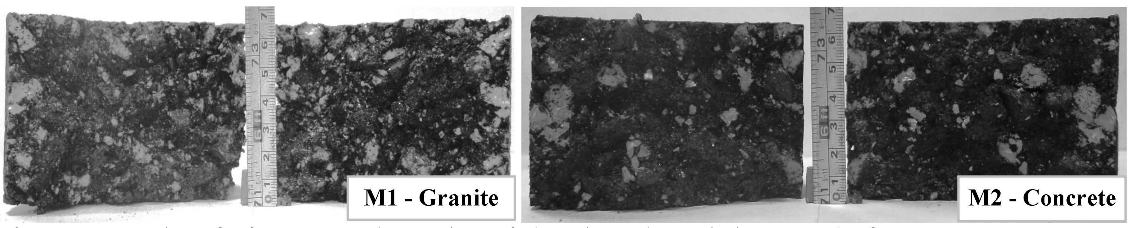

Figure 4. Samples of mixtures M1 (natural granite) and M2 (recycled concrete) after ITS tests.

Table 3. Results of water sensitivity and indirect tensile strength test.

Mixture	Natural granite (M1)		Recycled concrete (M2)	
Conditioning	Wet	Dry	Wet	Dry
Air voids content (%)	4.9	5.3	2.9	2.9
Bulk density (Kg/m^3)	2293	2273	2257	2261
Maximum density (Kg/m^3)	2406	2406	2330	2330
Indirect tensile strength, ITS (kPa)	1604	2135	1657	2259
Water sensitivity, ITSR (%)	75	-	73	-

The results show that the two mixtures evaluated in this study have a good mechanical performance and have very similar properties concerning their expected durability (indirect tensile strength values between 2135 kPa and 2260 kPa and water sensitivity ITSR values between 73% and 75%). However, it is essential to take into account that the M2 mixture with recycled concrete used a higher binder content (an increase of 26%), which would have supported these good results for M2 mix and its lower porosity (2.9% vs. 5.1% of the M1 mixture). Although the typical reference goal of 80% for ITSR has not been reached, it can be concluded that M2 can be applied because it behaves as well as the control mixture only with natural granite (M1).

4 CONCLUSIONS

This work investigated the properties of recycled concrete, as one of the main CDW materials, to study the viability of its use as part of the aggregates (up to 30%) in asphalt mixtures.

It was concluded that recycled concrete could be easily crushed to obtained a well-graded aggregate with a 0/14 size distribution, which can easily be incorporated up to 30% in the design of asphalt mixtures. The recycled concrete shape complies with the specified limits, and its affinity with bitumen is better than that of natural granite. However, recycled concrete is a porous cement composite material, with high water absorption and low wear resistance, and does not meet the specified limits for these properties. Thus, higher amounts of binder should be used in mixtures with recycled concrete, thus assuring good durability (ITS and ITSR values) in the pavement. Therefore, although recycled concrete should be applied prudently, up to 30% of this CDW can be successfully used as an alternative material to produce new asphalt mixtures.

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