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INDUSTRIAL SCALE PRODUCTION OF INNOVATIVE ASPHALT MIXTURES WITH STEEL SLAG AGGREGATES AND RECLAIMED ASPHALT

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ABSTRACT
This paper aims to assess and analyze the production and application of asphalt mixtures incorporating steel slag aggregates (SSA) and reclaimed asphalt (RA) at the industrial scale. The goal was to identify the main difficulties in translating the laboratory scale to the industrial scale and check for any differences in the application phase of these asphalt mixtures. Mechanical characterization of the trial section was also performed and analyzed. In this field trial, two types of asphalt mixtures were developed: i) an AC 20 asphalt mixture for the binder course with SSA, RA, and natural aggregates (NA); ii) an AC14 asphalt mixture for the surface course with SSA and NA. The experimental study comprised the volumetric characterization of the mixtures and water sensitivity and rutting resistance tests. The results showed that the performance of the developed mixtures is similar to that of conventional asphalt mixtures, which validates their application on a large scale. Also, these results can contribute to the future development of technical specifications for the design and quality control of asphalt mixtures with high amounts of alternative aggregates.

Keywords:
Asphalt mixtures; Steel slag aggregates; Reclaimed asphalt; Industrial scale; Field trial

INTRODUCTION
Nowadays, incorporating industrial by-products and alternative aggregates in asphalt mixtures is a relevant research theme [1]. Several authors have examined steel slag aggregates and reclaimed asphalt as potential alternatives, partially or entirely replacing natural aggregates in asphalt mixtures [2]. The use of SSA in hot mix asphalt (HMA) provides good affinity with bitumen, high stability, and resistance to rutting and fatigue cracking [3,4]. Besides, incorporating SSA and RA in HMAs also presents environmental advantages compared to conventional HMAs with natural aggregates.
After a previous study to optimize the mix design and mechanical performance of asphalt mixtures with SSA and RA in the laboratory [2], this paper presents the production and application of the studied asphalt mixtures at an industrial scale. This study aimed to evaluate more effectively and realistically the technical and mechanical quality of the asphalt mixture after application in a field trial. Furthermore, this work evaluates the feasibility and identifies difficulties in producing and applying asphalt mixtures with SSA and RA incorporation.
Finally, it is essential to state that full-scale trials, exemplified by the investigation detailed in this research paper, provide empirical evidence regarding the operational value of novel materials and ensure their practical application by validating their performance in real-scale scenarios.

RESEARCH METHODOLOGY
This work studied a pavement field trial section comprising asphalt mixtures with high recycled and artificial aggregate incorporation rates. An AC20 bin 50/70 mixture was applied for the binder course

with a minimum incorporation rate of 50% SSA and 15% RA (Fig. 1a). An AC14 surf 35/50 mixture was applied for the surface course with a minimum incorporation rate of 50% SSA (Fig. 1b).

(a) (b)

Fig. 1– Mixtures applied in the full-scale pavement trial: (a) AC20 mixture, (b) AC14 mixture.

This road trial was constructed in January 2023 within the premises of a construction company in Portugal. This localization was selected due to the heavy loads expected on this road. Then, the full-scale trial pavement was characterized by volumetric characterization, water sensitivity, and permanent deformation (i.e., wheel tracking) tests. In order to analyze and validate the developed asphalt mixtures, the results obtained in this study were compared to the results of conventional asphalt mixtures (AC14 and AC20) of a previous study [2].

PRODUCTION AND APPLICATION OF THE ASPHALT MIXTURES IN THE FIELD TRIAL

The production of asphalt mixtures with SSA and RA in an asphalt plant requires a prior study to optimize the translation of the laboratory to the industrial scale. Thus, this work was carried out to assess the conditions of the asphalt plant to incorporate SSA and RA without problems during operation. Moreover, since SSA has a higher density than natural aggregates (granitic and limestone), the rotation speed of the conveyor belts of each aggregates silo must be adjusted so that the particle size curve of the asphalt mixture produced would comply with the expected particle size distribution of each mixture [4]. The asphalt mixture application followed the traditional procedures, but some issues should be highlighted. Firstly, although the transport distance between the production site and the application site was 115 km, the temperature reduction of the asphalt mixture during transportation was not significant due to the positive influence of SSA material. Another concern is that this mixture is more difficult to compact due to SSA's hardness and rough shape. Therefore, the number of passes of the roller compactors should be increased during compaction.

MECHANICAL PERFORMANCE OF THE ASPHALT MIXTURES OF THE FIELD TRIAL

In order to evaluate the mechanical performance of asphalt mixtures, cylindrical specimens and prismatic slabs were extracted from the pavement for the following tests: Bulk density - BD (EN 12697 - 6), maximum density - MD (EN 12697 - 5), water sensitivity (EN 12697-12), and wheel tracking (EN 12697-22). Table 1 presents the results from the volumetric characterization and water sensitivity test of the studied asphalt mixtures and the results of the conventional mixtures from a previous study [2]. Fig. 2 presents a comparative graphic between the permanent deformation resistance of the selected mixtures and the conventional mixtures from the same study [2].

Table 1– Water sensitivity test results and volumetric characterization of the asphalt mixtures

Asphalt mixtures		Indirect Tensile Strength (kPa)		ITSR	Density (kg/m^3)		Voids
		ITS_d	ITS_w	(%)	MD	BD	(%)
AC 14 surf	SSA	2209	2177	99	3040	2783	8.5
	NA [2]	3218	2471	77	2449	2355	3.8
AC 20 bin	SSA + RA	2793	2581	92	2868	2701	4.9
	NA [2]	3074	1974	64	2452	2385	2.7

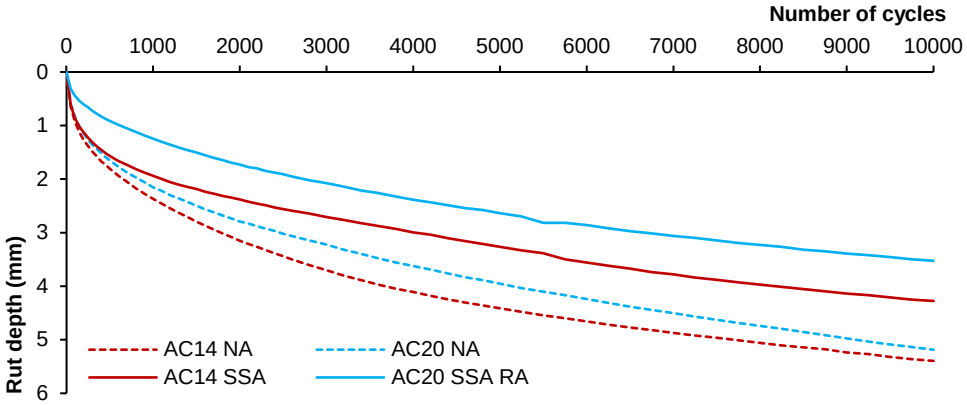

Fig. 2 – Evolution of the rut depth of the different asphalt mixtures in the wheel tracking test.

Based on the results obtained in the water sensitivity test, it can be seen that the mixtures studied presented significantly better results than the conventional mixtures. Regarding the air voids content of the mixtures, the mixture AC14 with SSA presents values above the maximum specification limit (5%), while the air voids content of the mixture AC20 with SSA and RA comply with the limits of the specifications [4]. Regarding the permanent deformation resistance test results, the asphalt mixtures with SSA performed better (i.e., lower deformations) than the conventional mixtures.

CONCLUSIONS

This study revealed significant insights into the performance of the studied asphalt mixtures. Based on the results obtained, it was concluded that the asphalt mixtures with SSA and RA are a viable solution from the mechanical point of view. It should be noted that the AC14 mixture with SSA did not fulfill the maximum air voids content limits, although it showed very positive results in the performance tests. Thus, this study suggests that the national specifications should be adapted to the arrival of innovative asphalt mixtures with high percentages of alternative aggregates, focusing more on the mechanical performance than in recipes in order to be able to contribute to a more sustainable construction without compromising the durability of road pavements.

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