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ASPHALT PAVEMENT RECYCLING WITH REGIONAL MATERIAL ANDADDITIONOF PORTLAND CEMENT CPII-Z40

RECICLAGEM DE PAVIMENTO ASFÁLTICO COM MATERIAL REGIONAL E ADIÇÃO DE CIMENTO PORTLAND CPII-Z40

RECICLAJE DE PAVIMENTO ASFÁLTICO CON MATERIAL REGIONAL Y ADICIÓN DE CEMENTO PORTLAND CPII-Z40

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ABSTRACT
Asphalt pavement recycling in the Amazon region emerges as a sustainable alternative by reusing existing materials and reducing environmental impacts. However, the humid climate and local logistical challenges pose difficulties for implementation. To overcome these issues, the cold in-place deep recycling method was adopted, minimizing material transport and environmental impact. At the Coari/AM Aerodrome, this technique was applied with the addition of Portland cement CPII-Z40. Initially, 3% cement was planned, but laboratory tests led to an increase to 4% to ensure strength and durability. The study followed the guidelines of DNIT Specification 167/2013-ES, with stages of soil-asphalt mixture characterization, specimen preparation, and performance analysis. The results showed an adequate gradation distribution, an optimum moisture content of 7.6%, and a maximum dry unit weight of 1.835 g/cm³. The technique proved effective and viable as a structural rehabilitation solution for flexible pavements in the region.

Keywords: Deeprecycling. Aerodrome. Paving. Coari/AM. Sustainability.

RESUMO
A reciclagem de pavimento asfáltico na Região Amazônica surge como uma alternativa sustentável, ao reaproveitar materiais existentes e reduzir impactos ambientais. Contudo, o clima úmido e as dificuldades logísticas locais impõem desafios à aplicação da técnica. Para contornar essas limitações, adotou-se o método de reciclagem profunda a frio “in situ”, que minimiza o transporte de materiais e os impactos ambientais. No Aeródromo de Coari/AM, essa técnica foi aplicada com a adição de cimento Portland CPII-Z40. Inicialmente, previa-se o uso de 3% de cimento, mas, após ensaios laboratoriais, a dosagem foi ajustada para 4% para garantir resistência e durabilidade. O estudo seguiu as diretrizes da Especificação

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de Serviço DNIT 167/2013-ES, com etapas de caracterização da mistura solo-asfalto, execução de corpos de prova e análise de desempenho. Os resultados demonstraram adequada distribuição granulométrica, teor de umidade ótima de 7,6% e massa específica seca máxima de 1,835 g/cm³. A técnica mostrou-se eficaz e viável como solução de reabilitação estrutural para pavimentos flexíveis na região.

Palavras-chave: Reciclagem Profunda. Aeródromo. Pavimentação. Coari/AM. Sustentabilidade.

RESUMEN

El reciclaje de pavimento asfáltico enlaregión amazónica surge como una alternativa sostenible al reutilizar materiales existentes y reducirlos impactos ambientales. Sin embargo, el clima húmedo y losdesafíos logísticos localesdificultansuimplementación. Para superar estos problemas, se adoptóel método de reciclaje profundo enfrío “in situ”, que minimiza el transporte de materiales y el impacto ambiental. Enel Aeródromo de Coari/AM, se aplicó esta técnica conlaadición de cemento Portland CPII-Z40. Inicialmente, se preveía el uso del 3% de cemento, pero losensayos de laboratoriollevaron a aumentar ladosificación al 4% para garantizarresistencia y durabilidad. El estudiosiguiólasdirectrices de laEspecificación de Servicio DNIT 167/2013-ES, con etapas de caracterización de lamezclasuelo-asfalto, preparación de especímenes y análisis de desempeño. Los resultados mostraron una distribución granulométrica adecuada, uncontenido óptimo de humedaddel 7,6% y una densidad seca máxima de 1,835 g/cm³. La técnica demostró ser eficaz y viable como solución de rehabilitaciónestructural para pavimentos flexiblesen la región.

Palabras clave: Reciclaje Profundo. Aeródromo. Pavimento. Coari/AM. Sostenibilidad.

1 INTRODUCTION

The recycling of asphalt pavement has stood out as a viable and sustainable alternative for the rehabilitation of deteriorated roads, as it reduces the need to extract new materials, promotes the appreciation of local resources, reduces environmental impact and transportation expenses.

The pavement is a structure composed of multiple layers of compacted materials, designed to resist the vertical forces coming from traffic and distribute them efficiently to the lower layers. In addition, it must provide good rolling conditions, comfort and safety to users, also resisting horizontal efforts and adverse weather conditions (Souza, 2020).

Over time, factors such as excess load, base failures, and climatic variations can cause deformations and deterioration in the pavement structure, requiring maintenance and recovery interventions. These interventions usually involve the removal of compromised layers and the application of new layers of coating, aiming to restore functionality and extend the life of the road (Silva, 2022).

Road pavement recycling is a sustainable technique that aims to reuse existing materials in asphalt coating, promoting the conservation of natural resources and reducing waste generation. The process consists of the reuse of degraded materials with the addition of binders, rejuvenators and, when necessary, granulometric recomposition, in order to restore the mechanical properties of the pavement (Cavalcante et al., 2024).

Thus, this research aims to recycle asphalt pavement with regional material and add Portland cement CPII-Z40 at the Coari/AM Aerodrome.

The combination of pavement recycling with local materials and the addition of cement contributes to improving the mechanical strength and durability of the recycled material, and can act as a stabilizing agent, allowing the production of pavement layers with good structural performance, meeting technical and environmental requirements. This technical combination presents itself as an efficient solution for maintenance and extension of the useful life of highways. Therefore, pavement recycling, when correctly applied, becomes a viable and environmentally responsible alternative in the context of highway maintenance and rehabilitation, especially in regions of difficult access or with logistical limitations.

2 THEORETICAL TABLEWORK

2.1 FLOORING

Airport pavements are designed to ensure adequate capacity to support loads from aircraft traffic, in addition to providing a firm, stable and regular surface. They must also be stable enough to resist the abrasive action of traffic, adverse weather conditions and other deteriorating agents without damage. To achieve these objectives, effective coordination between design, construction, and inspection factors is critical (FAA, 2009).

According to Grande and Carvalho (2020), the pavement is a structure built on earthworks intended to be technically and economically designed to resist the vertical forces arising from traffic and distribute them, improve rolling conditions in terms of comfort and safety, resist horizontal efforts (wear), making the rolling surface more durable.

These pavements can be classified as flexible, usually composed of granular layers and asphalt coating, or rigid, formed by concrete slabs. Both require specific technical criteria for sizing and maintenance, especially due to the concentrated and large loads imposed by aircraft (Bernucci et al., 2008; Pear tree; Lanças, 2012).

The airport pavement design process must consider a series of essential variables, such as the maximum takeoff weight of the aircraft (MTOW), the frequency of operations, the geotechnical properties of the subgrade and the climatic conditions of the region. To ensure the adequacy of the pavement structure to operational requirements, internationally recognized methods are used, such as the criteria established by the *Federal Aviation Administration* (FAA, 2009) and the ACN/PCN (*AircraftClassificationNumber/PavementClassificationNumber)* system, recommended by *the International Civil Aviation Organization* (ICAO, 2022).

Airport maintenance should be understood as a set of structured actions, with safety maintenance aimed at the immediate correction of critical anomalies, such as cracks and patches (Shahin, 2005; Veloso, 2001). The functional performance of the floor depends on the quality of the materials, the execution and a continuous technical maintenance program.

2.2 ASPHALT PAVEMENT RECYCLING

Asphalt pavement recycling (RAP) is an efficient and sustainable solution for road rehabilitation, motivated by economic and environmental factors and the scarcity of resources. Started in 1915 in the USA, it lost strength with the fall in the costs of new coatings, but gained prominence again in the 1980s, driven by environmental concerns and the search for more sustainable methods (Castro, 2003).

From a technical point of view, pavement recycling can occur through the partial or total reuse of materials from the coating, base and sub-base layers. After milling and disaggregation, the materials are mixed with new asphalt binders, rejuvenating agents or other additives, with or without particle size correction, which may also involve thermal processes (Momm; Domingues, 1995 *apud* Costa; Pinto, 2011, p. 196).

The relevance of asphalt recycling has been recognized at the national level by infrastructure agencies. DNIT Resolution No. 14:2021 established guidelines for the reuse of milled material in restoration and expansion works on federal highways, reinforcing the role of the technique as a strategy for sustainability and economic efficiency (DNIT, 2021).

The recycling of asphalt pavements has evolved from a contingency solution to a consolidated strategy in the context of contemporary engineering, combining technical performance, resource savings and environmental responsibility. Its expansion in Brazil depends on the continuity of investments in applied research, technical training and standardization of executive procedures.

Paiva and Oliveira (2010) developed a study in order to investigate the influence of compaction and optimal moisture content on the performance of recycled mixtures with Portland cement. For this, they performed simple compressive strength and diametrical compression tensile strength tests, at 7 days of curing, in samples compacted with *Modified Proctor* energy and compaction degrees between 90% and 100%, varying the humidity at ±1% of optimum. The mixtures contained 77% of asphalt milling, 20% of aggregate and 3% of cement. The results indicated that the mechanical strength increases proportionally to the degree of compaction, with the best performances obtained with moisture 1% above the optimum. The authors warn that the simple addition of cement may not guarantee improvement if the material is not properly compacted to reduce the voids in the mixture.

In another study, Paiva and Oliveira (2013) evaluated, in the laboratory, the recycling of soil-cement-based pavements. The mixture, composed of 30% asphalt coating and 70% base, was stabilized with 3% CP II-E 32 cement and tested with *Modified Proctor* energy. The simple compression and diametrical tensile tests, carried out after 7 days of curing, demonstrated that the cement content was sufficient to promote physicochemical reactions responsible for the strength gain. According to the authors, the granulometry of the material was essential for the good performance, since the soil-cement filled the voids left by the larger particles, favoring intergranular bonds. The reduced presence of silt and clay and the absence of plasticity also contributed to the increase in strength.

Fedrigo et al. (2016) developed a preliminary dosing method for recycled mixtures with cement addition, based on laboratory tests of particle size characterization. The authors demonstrated that the composition of the mixtures was adjusted in order to meet the ranges established in DNIT 167:2013ES, ensuring their technical application in the field.

Conrado (2021) analyzed the pavement recycling method with an emphasis on the importance of the milled particle size curve. The author points out that, if the materials do not fit into the ranges of DNIT 167:2013ES, it is necessary to add aggregates for correction, in order to ensure stability and performance of the recycled layer.

2.3 PORTLAND CLENT

The Brazilian Association of Portland Cement (ABCP, 2022) defines cement as "a fine powder, with agglomerating, binding or binding properties, which hardens under the action of water. In the form of concrete, it becomes an artificial stone, which can gain shapes and volumes, according to the needs of each work. Thanks to these characteristics, concrete is the second most consumed material by humanity, surpassed only by water."

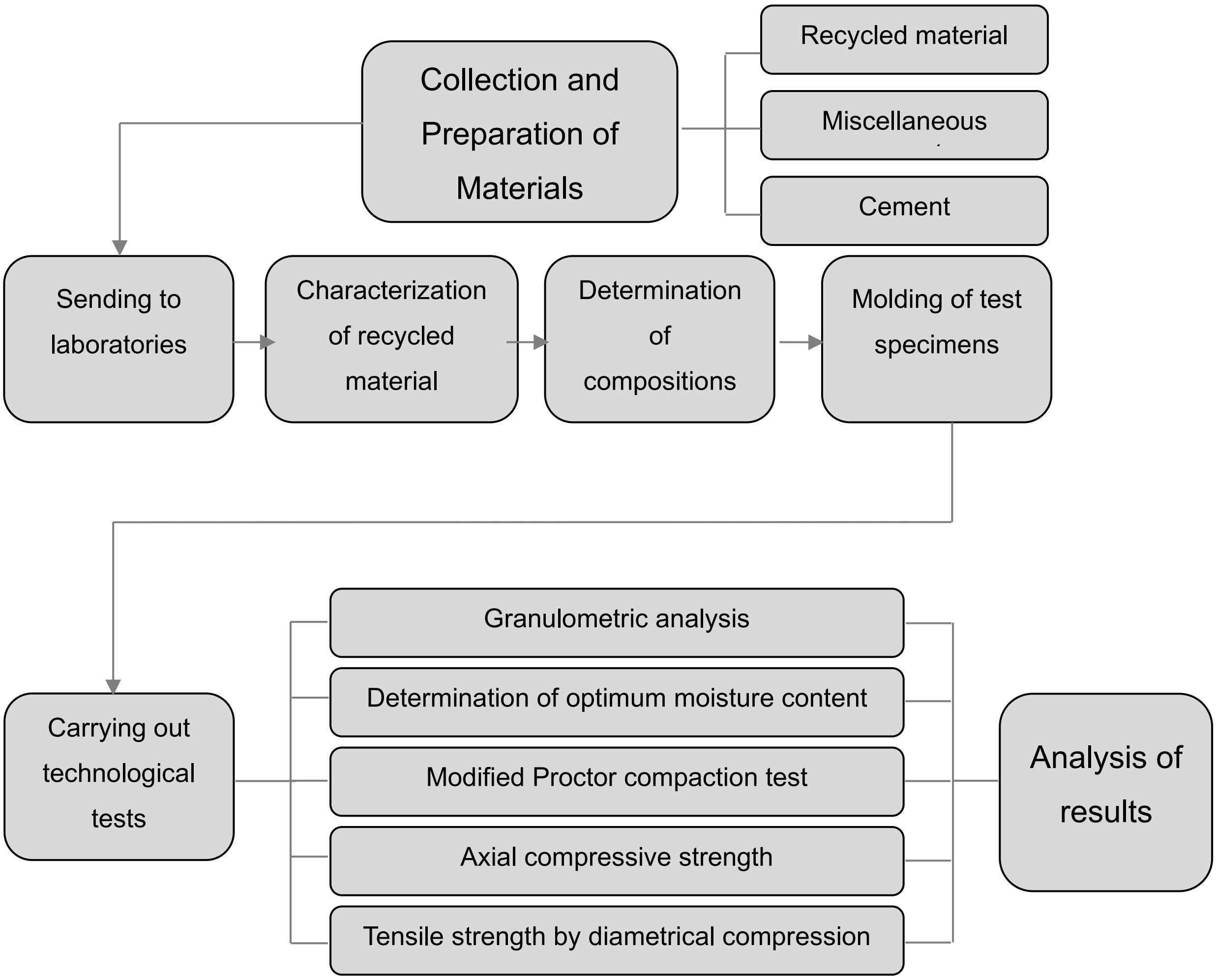
Cement is the main binding material used in civil engineering, being essential in the construction of infrastructure works, such as pavements, dams, buildings and airports. It is a fine powder obtained by grinding clinker, a product resulting from the calcination of limestone and clay, with the addition of small amounts of gypsum and, depending on the classification, additional materials such as slag, pozzolans or limestone filler (Neville; Brooks, 2013).

3 MATERIALS AND METHODS

This chapter describes the procedures adopted in the research, whose main objective is to evaluate the impact of the incorporation of milled asphalt pavement residue (RFA) on the properties of a *sand creet* soil, with the addition of 3% Portland cement. Figure 1 shows the stages of the research developed for the application of the pavement recycling technique at the Coari/AM airport.

Figure 1

Flowchart of the research stages



Source: Prepared by the authors.

Following the DNIT 167:2013-ES standard, the samples for the laboratory tests were collected with the same recycler used in the field, covering all structural variations of the pavement. About 150 kg of milled material (asphalt coating and soil-cement) were sent to the laboratory for characterization and testing, as shown in Figure 2.

Figure 2

Milled material

Source: Prepared by the authors

The dosage of the recycled mixture followed stages, according to the DNER-ME 201/1994 and DNIT 164/2013-ME standards, starting with the collection of material in a 35 cm layer, with a minimum mass of 7,000 g. After unraveling and sieving, the granulometry was adjusted by replacing the material retained in the 19 mm sieve with a fraction of 4.75 mm (ABNT NBR 7181:2025). 3% of the sample mass was removed, adding 210 g of CPII-Z40 Portland cement and 8% of water, with manual homogenization. Compaction followed the *Modified Proctor* method, with at least six specimens molded in five layers, totaling 9,925 g. Optimal moisture and dry specific mass were obtained according to ABNT NBR 12023:2012 and DNIT 167/2013-ES. Moisture was determined by the greenhouse (ABNT NBR 6457:2024) and "Speedy" (DNER-ME 052/1994) methods. The final compaction and strength tests (DNER-ME 201/1994 and 181/1994) followed DNIT 164/2013-ME. The characterization of the mixture was based on DNER-ME 080/1994 and the fineness modulus according to NBR 11579:2012 (corrected version: 2013). The simple axial compression (DNIT 143/2022-ES) and diametrical tensile (DNIT 136/2018-ME) tests evaluated the durability of the recycled layer.

4 RESULTS AND DISCUSSIONS

The analysis of the methodology adopted for the deep recycling of asphalt pavement *in situ*, with the addition of 3% Portland cement, is in accordance with the criteria established in the DNIT Service Specification 167:2013-ES. Chart 1 describes the fundamental steps provided for in the standard for the deep recycling process with chemical stabilization, highlighting those actually executed.

Table 1

Comparative Table DNIT standard with procedures executed

	Main steps of the deep recycling procedure of pavement in situ according to DNIT 167:Resu2013-ES	Steps taken
Steps prior to recycling	Collection of samples for the preparation of the dosing project	According to Geotechnical Survey
	Dosing design	Not realized
Steps during recycling	Spreading additional aggregates (where necessary)	Accomplished
	Spreading Portland cement over the surface at the rate indicated in the mixing design	Accomplished
	Maximum time between the application of the cement and the start of the mixing of the materials is 30 minutes	Accomplished
	Recycling of the pavement section: addition of water, mixing and homogenization of the mixture of the existing materials in the pavement with the additional aggregates	Accomplished
	Pre-compaction, carried out right after the recycler passes through	Accomplished
	Initial conformation of the transverse and longitudinal profiles of the layer using a motor grader	Accomplished
	Final compaction	Accomplished
	Final adjustment of the surface using a motor grader	Accomplished
	Protection of the recycled layer through the application of solvent-free asphalt product	Accomplished
	Controlling the recycled mix in the field	Accomplished
	Compaction control	Accomplished
Post-recycling steps	Application of the final coating on the recycled layer	Accomplished
	Controlling Recycled Mix in the Laboratory	Accomplished

Source: Prepared by the authors.

4.1 PARTICLE SIZE ANALYSIS

The granulometric strips aim to ensure an adequate distribution of grains, favoring the mechanical performance and workability of the soil-cement mixture. The results obtained in the test allowed us to verify whether the recycled material collected in the municipality of Coari/AM meets the requirements of Range I or II of the DNIT 167:2013-ES standard, as specified in Table 1. This classification directly influences the cement content to be added, as well as the methodology to be adopted for compaction and curing of the mixture.

Table 2

Particle size ranges to be met by DNIT Standard 167:2013-ES

Mesh sieve Square		Percentage passing, Mass (%)		Band tolerance (%)
		Tracks		
ASTM	Aperture (mm)	I	II	
2"	50,8	100	100	-
1"	25,4	75-90	100	± 7
3/8"	9,5	40 - 75	50 - 85	± 7
No. 4	4,8	30 - 60	35 - 65	± 5
Issue 10	2	20 - 45	25 - 50	± 5
Issue 40	0,42	15 - 30	15 - 30	± 2
Issue 200	0,074	5 - 15	5 - 15	± 2

Source: DNIT (2013).

The values generated through the granulometric analysis of the recycled material were used to evaluate the relationship of the curve obtained for the recycled mixture (soil + asphalt coating), fitting it into one of the ranges stipulated by Table 1 of DNIT Specification 167:2013-ES, as shown in Table 2.

Table 3

Granulometry of the recycled material

Location: Coari/AM			**Hole No. Recycled Material**		
Reg. No.: 001 Material Testing recycled			Operator:		
SIEVING OF THE TOTAL SAMPLE					
Total Dryness (g)	5000				
SIEVES		RETAINED MATERIAL			% That Exceeds Total Sample
No.	Mm	Weight (g)	% Total Sample	Cumulative %	
2"	50,8	0	0,00	0,00	100,00
1"	25,4	80	1,60	1,60	98,40
3/8"	9,5	618,3	12,37	13,97	86,03
No. 4	4,8	570,7	11,41	25,38	74,62

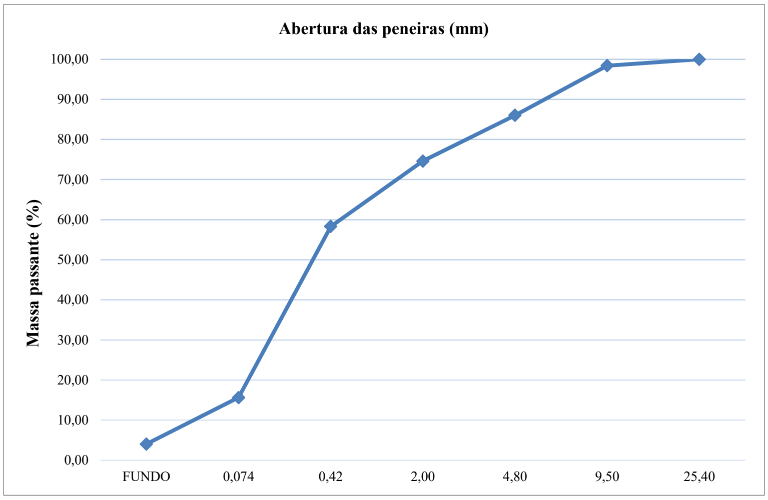
Issue 10	2,0	816,2	16,32	41,70	58,30
Issue 40	0,42	2133,3	42,67	84,37	15,63
Issue 200	0,074	579,1	11,58	95,95	4,05
BOTTOM	X	202,4	4,05	100,00	X

Source: Airports Commission of the Amazon Region (2023)

Figure 3 shows the particle size curve of the recycled coating and base mixture, considering the entire thickness (100%) of the layer (10 cm of CBUQ) and the entire thickness (100%) of the base (25 cm of Sand-Creet).

Figure 3

Granulometric curve of the recycled mixture (Cover + Base)

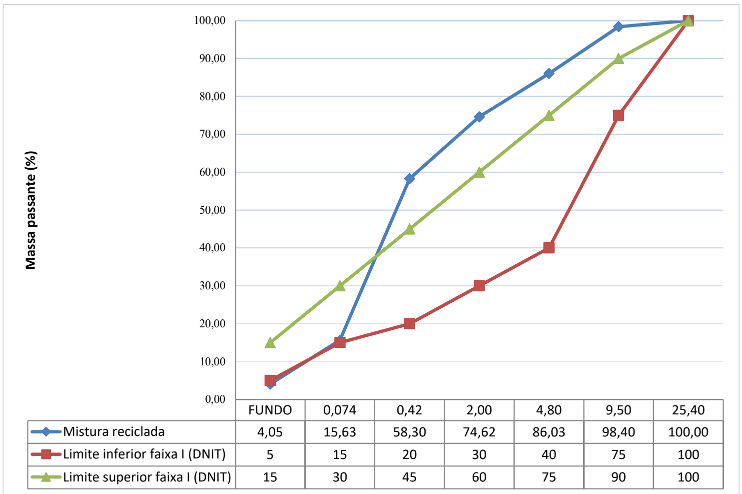


Source: Prepared by the authors.

When comparing the particle size curve of the recycled mixture with the ranges established by the DNIT 167:2013-ES standard, as shown in Table 1, Figures 4 and 5 show a significant variation in relation to the limits of these ranges. The comparison with the lowest discrepancy was in relation to the Particle Size Range II; however, even considering the tolerance range provided for in Table 1, it would still be necessary to make adjustments so that the material met the required framing criteria.

Figure 4

Particle size curve of the recycled mixture and particle size range I of the DNIT 167:2013 standard – ES

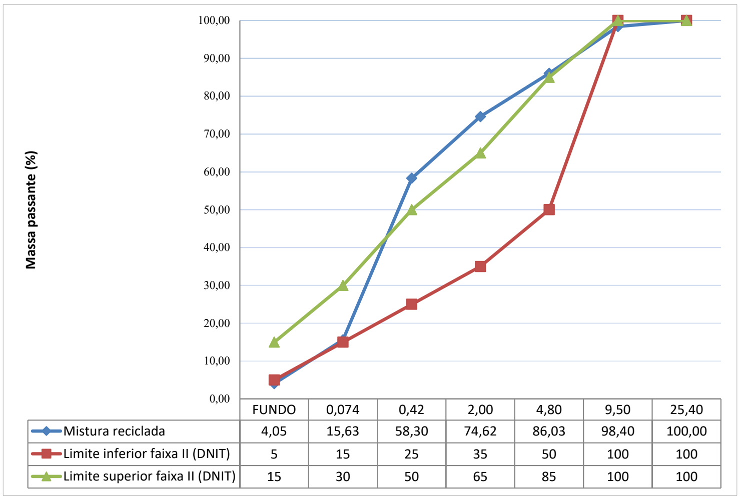


	FUNDO	0,074	0,42	2,00	4,80	9,50	25,40
Mistura reciclada	4,05	15,63	58,30	74,62	86,03	98,40	100,00
Limite inferior faixa I (DNIT)	5	15	20	30	40	75	100
Limite superior faixa I (DNIT)	15	30	45	60	75	90	100

Source: Prepared by the authors.

Figure 5

Particle size curve of the recycled mixture and particle size range II of the DNIT 167:2013 standard – ES



	FUNDO	0,074	0,42	2,00	4,80	9,50	25,40
Mistura reciclada	4,05	15,63	58,30	74,62	86,03	98,40	100,00
Limite inferior faixa II (DNIT)	5	15	25	35	50	100	100
Limite superior faixa II (DNIT)	15	30	50	65	85	100	100

Source: Prepared by the authors.

In many cases, the granulometric correction of the material from the milling process must be carried out, since, after roughing, the mixture has particles of high granulometry. In these cases, particle size stabilization is necessary, followed by mechanical stabilization by compaction, in order to obtain high values of strength and rigidity, reflecting on the structural performance of the new pavement (Specht, 2013).

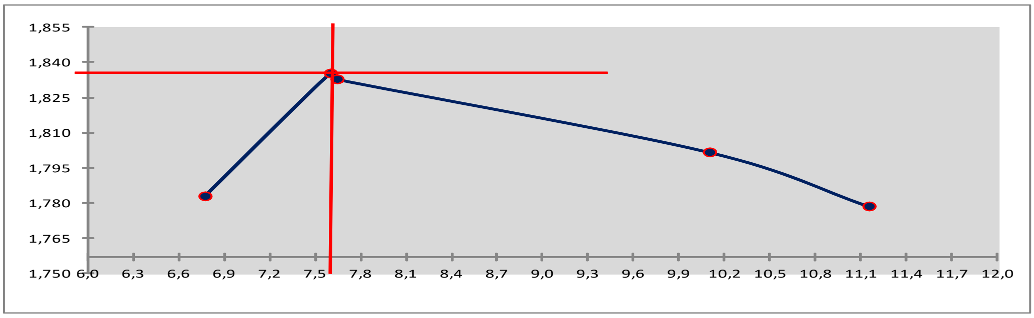
4.2 OPTIMUM MOISTURE CONTENT AND MAXIMUM SPECIFIC MASS

As shown in Figure 6, the values obtained for optimal moisture (7.6%) and maximum dry specific mass (1.835 g/cm³), determined according to ABNT NBR 7182:2025, served as a reference for the molding of the specimens used in the mechanical tests. These parameters ensured the proper compaction of the samples, ensuring the reliability of the results in the simple compressive strength and diametrical compression tensile strength tests. The data obtained are compatible with those found in the literature, reflecting ideal conditions for the performance of the recycled layer in the field.

Figure 6

Determination of optimum moisture and specific mass

			CILINDRO	Nº		4					
				Peso		5270					
				Volume		2.304,51					
Peso da Amostra Compactada e Cilindro	Peso da Amostra Compact.	Massa Específica Aparente do Solo Úmido	DETERMINAÇÃO DA UMIDADE								Massa específica Aparente Seca
			Nº DA CAPSULA	PESO DA CAPSULA	PESO DA CAPSULA E SOLO ÚMIDO	PESO DA CAPSULA E SOLO SECO	PESO DA ÁGUA	PESO DO SOLO SECO	TEOR DE UMIDADE	FATOR DE CORRECÃO (100/100+h)	
g	g	g/cm3		g	g	g	g	g	%		g/cm3
9800	4530	1,966	11	55,00	680,00	639,40	40,60	584,40	6,9	0,935	1,783
			13	50,00	585,00	551,90	33,10	501,90	6,6	0,938	
9970	4700	2,039	21	17,70	124,20	117,20	7,00	99,50	7,0	0,934	1,835
			27	30,90	121,00	114,20	6,80	83,30	8,2	0,925	
9970	4700	2,039	21	17,70	124,20	117,00	7,20	99,30	7,3	0,932	1,833
			27	30,90	121,00	114,30	6,70	83,40	8,0	0,926	
10055	4785	2,076	65	30,80	113,40	105,70	7,70	74,90	10,3	0,907	1,802
			02	17,70	114,10	105,40	8,70	87,70	9,9	0,910	
10060	4790	2,079	05	31,00	131,60	121,30	10,30	90,30	11,4	0,898	1,779
			10	18,30	123,10	112,80	10,30	94,50	10,9	0,902	



	RESULTADOS
	Massa Específica Aparente Máxima do Solo Seco
	= 1,835 g/cm3
	Umidade Ótima
3S QSS SPV ANDERSON DA SILVA GOMES	h= 7,6 %

Source: Airports Commission of the Amazon Region (2023).

4.3 AXIAL COMPRESSIVE STRENGTH AND DIAMETRICAL COMPRESSION TENSILE STRENGTH

At the initial dosage of 3% cement, the specimens presented an average simple compressive strength of 1.96 MPa (Figure 7), a value below the minimum required by the standard (2.1 MPa). In addition, the tensile strength by diametrical compression was 0.35 MPa (Figure 8), indicating an instability of the mixture and structural compromise of the recycled layer.

After readjusting the dosage to 4%, the new specimens showed significantly higher performance. The simple compressive strength reached an average of 2.35 MPa (Figure 7), with the DNIT 167:2013-ES recommended for 2.1 to 2.5 MPa, while the tensile strength by diametrical compression stabilized at 0.28 MPa, within the range recommended by the aforementioned standard, which is 0.25 to 0.35 MPa.

Figure 7

Axial compressive strength

Source: Prepared by the authors.

Figure 8

Tensile strength by diametrical compression

Source: Prepared by the authors.

Of the test specimens tested, with the addition of 3% Portland cement CPII Z40, only one did not reach the minimum strength specified in the ABNT NBR 7215:2025 standard. The results of the burst tests are consolidated in the spreadsheet shown in Figure 9.

Figure 9

Sample result of the recycled material (cover + base)

ROMPIMENTO

REG.Nº 001	MATERIAL RECICLADO	16/06/2023
		DATA
CABECEIRA	CAPA + BASE	
LOCAL	TIPO DE MATERIAL	OPERADOR
COARI - AM		
CIDADE ESTADO	INTERESSADO	RESP. TÉCNICO

Data da Moldagem	Data da Ruptura	Idade de Ruptura	Tipo de Ruptura	Carga de Ruptura (Kgf)	Tensão de Ruptura (Mpa)
09/06/2023	16/06/2023	7	Comp. Simples	1,16	1,45
09/06/2023	16/06/2023	7	Comp. Simples	1,72	2,15
09/06/2023	16/06/2023	7	Comp. Simples	1,83	2,28
09/06/2023	16/06/2023	7	Comp. Diametral	1,19	0,37
09/06/2023	16/06/2023	7	Comp. Diametral	1,03	0,32
09/06/2023	16/06/2023	7	Comp. Diametral	1,20	0,37

Source: Airports Commission of the Amazon Region (2023).

5 CONCLUSION

Deep recycling *in situ* with the addition of Portland cement on the pavement of Coari-AM Airport proved to be technically, economically and environmentally viable, as long as it is accompanied by adequate planning and control. In this study, it can be seen that the absence of a previous dosage study compromised the mechanical strength and granulometry. The initial dosage of 3% cement was insufficient, and it was necessary to raise it to 4%, which increased cement consumption by approximately 33.34% in relation to the amount initially planned, causing an impact on costs and CO_2 emissions. Thus, the need to Table the granulometry of the recycled material is emphasized, considering bands I and II of the DNIT 167:2013 – ES standard, even if it is necessary to add aggregates. The addition of regional aggregates, such as gravel, could have improved the grain size and reduced the need for cement. The use of local kaolin in the sub-base reinforces the sustainability of the solution. The technique contributes to the Sustainable Development Goals (SDGs), especially SDGs 9 (industry, innovation and infrastructure), 11 (sustainable cities and communities), 12 (responsible consumption and production) and 13 (action against global climate change). The replication of the methodology, with improvements, can benefit other works in the Amazon.

From this research, it can be concluded that the application of the pavement recycling technique constitutes a viable technological solution for situations of logistical isolation, such as aerodromes in the Amazon, in addition to minimizing the environmental impacts resulting from the extraction of non-renewable resources that constitute the raw material of road works/construction. It is worth mentioning that although the recycling of materials is advantageous, it is necessary to be accompanied by a strict technological laboratory control before and during the work to ensure the useful life and usefulness of the same (landing strip/pavement) and thus ensure the safety, comfort and economy of the road system under study. The research has limitations, such as the lack of support for more detailed laboratory analysis, due to the logistical condition. An important contribution to future work is the creation of a manual that specifies the laboratory standards and the executive process to be carried out with versatility and to carry out mixtures tests using artificial intelligence trained for analysis.

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REFERENCES

Associação Brasileira de Cimento Portland. (2022). Cimento Portland: O que é e para que serve. São Paulo: ABCP.

Associação Brasileira de Normas Técnicas. (2012). NBR 11579: Cimento Portland – Determinação do índice de finura por meio da peneira de 75 µm (nº 200). Rio de Janeiro: ABNT. Errata 1: 2013.

Associação Brasileira de Normas Técnicas. (2012). NBR 12023: Solo – Ensaio de compactação. Rio de Janeiro: ABNT.

Associação Brasileira de Normas Técnicas. (2024). NBR 6457: Amostras de solo – Preparação para ensaios de compactação, caracterização e determinação do teor de umidade. Rio de Janeiro: ABNT.

Associação Brasileira de Normas Técnicas. (2025). NBR 7181: Solo – Análise granulométrica. Rio de Janeiro: ABNT.

Associação Brasileira de Normas Técnicas. (2025). NBR 7182: Solo – Ensaio de compactação. Rio de Janeiro: ABNT.

Associação Brasileira de Normas Técnicas. (2025). NBR 7215: Cimento Portland – Determinação da resistência à compressão de corpos de prova cilíndricos. Rio de Janeiro: ABNT.

Bernucci, L. L., Motta, L. M. G., Ceratti, J. A. P., & Soares, J. B. (2008). Pavimentação: Fundamentos e dimensionamento (2nd ed.). São Paulo: Oficina de Textos.

Castro, F. M. A. (2003). Reciclagem de pavimentos asfálticos [Master's thesis, Universidade de São Paulo]. Repositório USP. https://www.teses.usp.br/

Castro, S. D. (2003). Reciclagem de pavimentos asfálticos: Processo a quente [Master's thesis, Universidade Federal do Rio de Janeiro]. Repositório UFRJ. https://www.repositorio.ufrj.br/

Cavalcante, J. V. S., Silva, A. B., Oliveira, C. D., & Santos, R. P. (2024). Eco-inovação em pavimentação: Maximizando sustentabilidade e eficiência com uso de material fresado rejuvenescido e reciclado no estado de Goiás. Contribuciones a las Ciencias Sociales, 17(7), e8468. https://www.researchgate.net/publication/382318014

Conrado, N. M. (2021). Análise do método de reciclagem de pavimento com adição de cimento Portland [Master's thesis, Universidade Federal Rural do Semi-Árido]. Repositório UFERSA. https://repositorio.ufersa.br/

Departamento Nacional de Estradas de Rodagem. (1994). DNER-ME 052: Solos – Determinação do teor de umidade com emprego do "Speedy" – Método de ensaio. Rio de Janeiro: DNER.

Departamento Nacional de Estradas de Rodagem. (1994). DNER-ME 080: Solos – Análise granulométrica por peneiramento – Método de ensaio. Rio de Janeiro: DNER.

Departamento Nacional de Estradas de Rodagem. (1994). DNER-ME 181: Solos – Solos estabilizados com cinza volante e cal hidratada – Determinação de resistência à compressão simples – Método de ensaio. Rio de Janeiro: DNER.

Departamento Nacional de Estradas de Rodagem. (1994). DNER-ME 201: Solos – Solo cimento – Compressão axial de corpos de prova cilíndricos. Rio de Janeiro: DNER.

Departamento Nacional de Infraestrutura de Transportes. (2013). DNIT 164 – ME: Solos – Compactação utilizando amostras não trabalhadas – Método de ensaio. Rio de Janeiro: DNIT.

Departamento Nacional de Infraestrutura de Transportes. (2013). DNIT 167 – ES: Pavimentação: Reciclagem profunda de pavimentos "in situ" com adição de cimento Portland – Especificação de serviço. Brasília: IPR/DNIT.

Departamento Nacional de Infraestrutura de Transportes. (2018). DNIT 136 – ME: Pavimentação asfáltica – Misturas asfálticas – Determinação da resistência à tração por compressão diametral – Método de ensaio. Rio de Janeiro: DNIT.

Departamento Nacional de Infraestrutura de Transportes. (2021). Reciclagem de material asfáltico reduz custos e impactos ambientais. Revista Caminhoneiro. https://www.revistacaminhoneiro.com.br/reciclagem-de-material-asfaltico-reduz-custos-e-impactos-ambientais

Departamento Nacional de Infraestrutura de Transportes. (2021). Resolução nº 14, de 6 de abril de 2021: Estabelece diretrizes para o reaproveitamento de material fresado em obras rodoviárias. Diário Oficial da União, seção 1, 65, 165.

Departamento Nacional de Infraestrutura de Transportes. (2022). DNIT 143 – ES: Pavimentação – Base de solo cimento – Especificação de serviço. Rio de Janeiro: DNIT.

Federal Aviation Administration. (2009). Advisory Circular AC 150/5320-6E: Airport pavement design and evaluation. Washington, DC: FAA. https://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5320_6e.pdf

Fedrigo, W., Bressiani, J. C., & Balbo, J. T. (2016). Reciclagem de pavimentos com adição de cimento: Proposição de um método de dosagem preliminar. ResearchGate. https://www.researchgate.net/publication/312167271

Grande, W. G., & Carvalho, L. C. (2020). Avaliação superficial de patologias em pavimento flexível: Estudo de caso em um trecho da Av. Celina Ferreira Otoni, Varginha, MG. [Unpublished manuscript].

International Civil Aviation Organization. (2022). Aerodrome design manual – Part 3: Pavements. Montreal: ICAO.

Momm, M. F., & Domingues, A. (1995). Pavimentação ecológica: Reciclagem de pavimentos asfálticos. In Seminário de Infraestrutura Viária (pp. 1–10). São Paulo: DNIT.

Neville, A. M., & Brooks, J. J. (2013). Concrete technology (2nd ed.). Essex: Pearson Education.

Paiva, A. C. C., & Oliveira, J. R. M. de. (2013). Estudo da reciclagem de pavimento com adição de cimento. Revista Transportes, 21(2), 55–65. https://www.revistatransportes.org.br/anpet/article/view/902

Paiva, J. A. C., & Oliveira, L. A. P. (2010). Análise da influência da compactação e da umidade ótima no desempenho de misturas recicladas com cimento Portland. Revista Transporte & Desenvolvimento, 6(2), 47–60. https://www.revistas.unesp.br/index.php/transp/article/view/2279

Shahin, M. Y. (2005). Pavement management for airports, roads, and parking lots (2nd ed.). New York: Springer.

Silva, E. P. da. (2022). Patologias em pavimento flexível [Undergraduate thesis, Faculdade Pitágoras]. Repositório PGSScogna. https://repositorio.pgsscogna.com.br/bitstream/123456789/61926/1/EVELTON_PEREIRA_DA_SILVA.pdf

Souza, J. B. de. (2020). Técnicas e procedimentos de manutenção de pavimentos asfálticos [Undergraduate thesis, Faculdade Pitágoras]. Repositório PGSScogna. https://repositorio.pgsscogna.com.br/bitstream/123456789/43368/1/JAQUELINE_BEGALLI_DE_SOUZA.pdf

Specht, L. P. (2013). Contribuição ao estudo da reciclagem de pavimentos asfálticos com adição de cimento Portland [Master’s thesis, Universidade Federal do Rio Grande do Sul]. Lume UFRGS. https://www.lume.ufrgs.br/handle/10183/71995