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Use of aggregates from construction waste in asphalt paving base

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ABSTRACT

Nowadays, with the growing increase in the urban demographic aspect, it is a social priority to propose measures to mitigate the problems encountered and to subsidize actions, in order to correct and avoid future complications in areas conducive to urban expansion.

Keywords: Construction, Asphalt, Characterization.

1 INTRODUCTION

Nowadays, with the growing increase in the urban demographic aspect, it is a social priority to propose measures to mitigate the problems encountered and to subsidize actions, in order to correct and avoid future complications in areas conducive to urban expansion.

Because of this growth, local municipalities have been striving to increase and improve local infrastructure. However, the cost of this improvement is too high for the public coffers, with research as alternatives to reduce, for example, the costs of paving.

According to Roza (2018), more than 80% of the materials that make up the pavement layers of highways and streets are crushed materials. In addition, the search for the application of the concepts of sustainability and the reuse of materials and various waste has also been an important theme in paving. The volume of natural materials that have been used in the thousands of kilometers of existing Brazilian highways and the need to build duplications or even expand the paved network is very large.

Among such alternatives, the use of waste from civil works construction (RCC) for road paving is a great concept that ends up reducing the volume of garbage and debris from civil constructions, reducing costs for municipalities with material clandestinely deposited along public roads, vacant lots, watercourses and slopes, reduce the cost of its use as a source of raw material for road paving, in addition to raising awareness among the population about sustainability (TAMURA, 2015).

More than half of construction waste is disposed of clandestinely and irregularly in Brazil. The country recycles only 16% of the total construction waste generated. Rubble recycling plants produce 25 million cubic meters of recycled aggregate; product from the recycling of rubble and that can replace the natural aggregate of quarries or sand ports (ABRECON, 2021).

One of the options for using the RCC, especially in small municipalities, is in paving side roads, because in this case, even processing plants and more expensive equipment can be dispensed with (TAMURA, 2015).

According to NBR 15115 (2004), the recycled aggregate usable in paving is the granular material, obtained through crushing or mechanical processing, from civil construction waste, Class A of CONAMA Resolution 307. Just like conventional materials, the material from recycling must also meet requirements such as: good particle size graduation; minimum CBR values (since the regulations have not yet been updated in relation to resilience modulus tests) and maximum expansion values (depending on the type of pavement layer); and maximum characteristic dimension of 63.5mm.

The base of a pavement is a layer intended to resist the vertical forces coming from vehicles, distributing them appropriately to the underlying layer, executed on the sub-base (when necessary), subgrade or reinforcement of the subgrade duly regularized and compacted (DNIT 141/2010-ES).

The materials that usually make up the granular bases or sub-bases are soil, soil mixture, rock crushing products, pebbles and sands. In addition, these layers can be made up of other combinations of materials, as long as they have the appropriate stability and durability to resist the stresses required on them (BERNUCCI et al., 2006).

According to Carneiro *et al*. (2001) The use of recycled aggregates in asphalt paving has economic, social and environmental advantages, being one of the most used purposes today. However, the exclusive use of this aggregate to constitute the paving layers may be unfeasible due to non-compliance with the specifications given by the standards, and it is necessary to constitute a trace with the soil used and the RCC for it to be improved.

In this work, an optimal mixture of soil-RCC aggregate was determined using the soil collected at IFSP, Votuporanga Campus, and recycled aggregate provided by the Mejan Environmental Company, from Votuporanga, with the objective of using local recycled material, in order to meet the specifications for its use as a paving base. It is worth informing here that the company Mejan Ambiental is supporting the present work, with the supply of recycled aggregates.

Therefore, considering what has been presented, the present work aims to contribute to the proper disposal of waste from civil construction and preservation of resources from non-renewable sources, since it proposes to incorporate such waste into the base layer of pavements.

2 OBJECTIVE OR PROPOSITION

The purpose of this work is the production of a base layer for flexible asphalt paving using aggregates from recycling construction and demolition waste in partial replacement of gravel. For this, tests were carried out to determine the best dosage in the Soil-RCC mixture, in view of the minimum parameters for a paving base.

3 ACTIVITIES CARRIED OUT

Activity 1 - Literature review based on the results of research already carried out and standards: The first activity carried out was a study of all the materials found on tests and dosages already carried out, so that, based on this analysis, the dosage of this project could be as close as possible to the actual dosage used and accepted by DNIT.

Activity 2 – Preparation and characterization of the soil and natural and recycled aggregates: From the soil characterization, the best dosages for the soil-RCC mixture were analyzed, in order to verify the support potential of the mixture in paving layers. The bearing capacity of the soil was studied by means of the California Support Index (ISC) test, performed in accordance with NBR 9895:2016. The assays will follow the DNIT standards listed below:

1) Particle size analysis (NBR 7181:2018), whose results were analyzed according to DNIT 141/2010-ES.
2) Consistency limits (or Atterberg limits), applying NBR 6459:2016 (Liquidity Limit) and NBR 7180:2016 (Plasticity Limit). The results were compared with DNER 122/94 and DNER-ME 082/94.
3) California Expansion and Support Index (ISC or CBR), recommended by NBR 9895:2016, whose results were based on DNIT 141/2010-ES and DNIT 139/2010-ES.4.

Activity 3 – Tests of the different mixtures for the base layer: With the results of the characterization of the soil and the aggregates, the CBR test was carried out in the soil/RCC mixtures considering the respective percentages of 20/80, 40/60, 60/40 and 80/20.

Activity 4 – Study of the base layer: Once the optimal percentage of the soil/RCC mixture was defined, the base layer was prepared with a mixture of 50% gravel 1 and 50% soil-RCC. The study of the base layer followed the recommendations of the DNIT 141/2010-ES standard. From this standard, having the N of traffic calculated according to the USACE methodology, the granulometry and also the parameters that the base must meet were defined.

After that, the ISC test was performed in the mixture, and a value higher than 60% or 80% was recommended in the base layer, depending on the N of traffic found. (DNIT 141/2010-ES).

The expansion test, obtained at the beginning of the ISC determination test, should present a value ≤ 0.5%, according to the DNIT 141/2010-ES standard for the structural function of the base of a floor.

From the LL (Liquidity Limit) and LP (Plasticity Limit) tests, it was verified if the mixture is suitable for use in the base layer, limiting the LL value to 25% and the LP value to 6%, as specified by the DNER 122/94 and DNER-ME 082/94 standards, respectively.

Activity 5 – Cost comparison analysis: At the end of the tests, a simple cost comparison was made between a base layer made with gravel 1 plus a mixture of soil and recycled aggregates, in the optimal percentage found, and another layer made only with natural aggregate, i.e., gravel 1. A simple dummy project was used for the purpose of calculating and comparing actual values.

4 RESULTS OBTAINED

4.1 AGGREGATE AND SOIL CHARACTERIZATION TESTS

Before starting the characterization of the materials, they were dried. The granulometry test, performed by sieving the sample, as shown in Figure 1, resulted in a maximum diameter of 9.5 mm and a minimum of 0.3 mm for the recycled aggregate, classifying it as crushed stone 0, which is used in the standard base layers. As for the granulometry of the soil, it was classified as clay soil, composed of more than 30% of clay, aluminum and iron, and granulometry of up to 0.005mm per grain. The natural aggregate was classified as gravel 1, with a diameter between 9.5mm and 19mm.

Figure 1. Particle size analysis of RCC by sieve.

Source: The author

Once the particle size characterization of the aggregates was completed, the soil characterization began with the Atterberg limit tests, and the liquidity limit was performed according to ABNT NBR 7180 and the plasticity limit according to ABNT NBR 6459, allowing the subsequent analysis of the soil support index.

The equipment used to determine the liquidity and plasticity limits, as well as the template and soil sample used are shown in Figure 2.

Values of 15.6% and 4.9% were found, respectively, for the limits of liquidity and plasticity. Thus, it is possible to state that the mixture is suitable for use in base layer, since the standards DNER 122/94 and DNER-ME 082/94, limit, respectively, to 25% the value of LL and 6% to the value of LP.

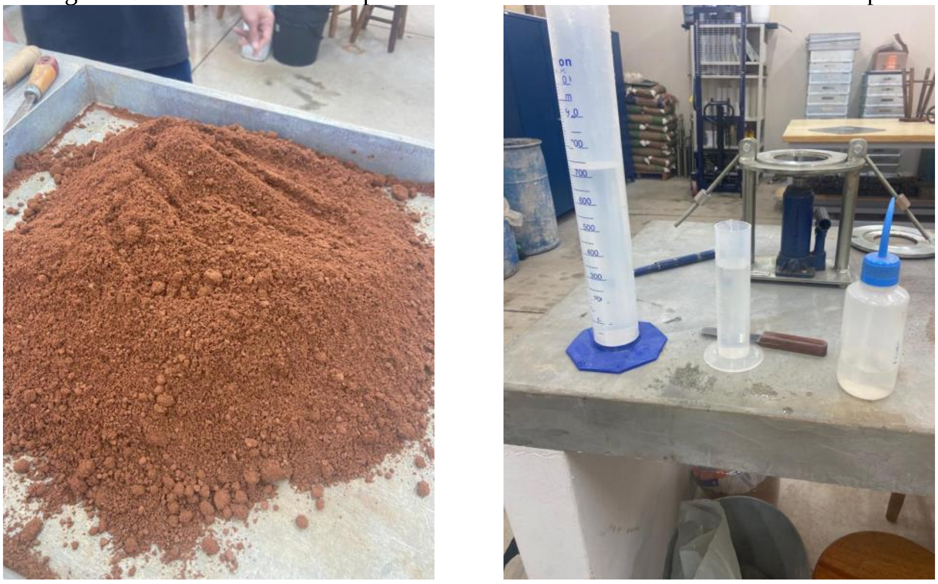
Figure 2. Equipment used in the Atterberg limits test (left) and template and soil sample used (right).

Source: The author

For the compaction test, a cylinder with a volume equal to 2100cm³ or 0.0021m³ was used, the large proctor, with intermediate energy and with soil reuse, being made 5 layers, each receiving 26 strokes, as established by NBR 7182:2016, for each moisture content evaluated, proceeding to the gradual increase of water in the soil.

Figure 3 shows the humidified soil sample and the equipment used to add water. Figure 4 illustrates the molding of the ground specimen with a large Proctor.

Figure 3. Humidified soil sample and containers used to add water to the sample.



Source: The author

Figure 4. Specimen molding with the use of a proctor.

Source: The author

Tables 1 and 2 show the results used to determine the optimum moisture content by means of compaction tests and moisture values and apparent specific weight.

Table 1. Data obtained through the compaction test

Corpos de prova	Massa (KG)	Volume (L)	Gama n (KG/L)	Cápsula (g)	Peso Pi (g)	Peso Pf (g)
1	3,552	2,1	1,69	11,43	26,76	25,97
2	3,812	2,1	1,82	6,02	19,45	18,58
3	4,004	2,1	1,91	5,37	13,45	12,75
4	4,092	2,1	1,95	5,48	18,51	17,29
5	4,112	2,1	1,96	12,37	27,02	25,38
6	4,076	2,1	1,94	12,19	33,86	31,23

Table 2. Moisture values (h) and Specific weight (range d) calculated using the data in Table 1.

Corpos de prova	Pi (g)	Pf (g)	Pa (g)	h (%)	Gama d (Kg/L)
1	15,33	14,54	0,79	5,43	1,60
2	13,43	12,56	0,87	6,93	1,70
3	8,08	7,38	0,7	9,49	1,74
4	13,03	11,81	1,22	10,33	1,77
5	14,65	13,01	1,64	12,61	1,74
6	21,67	19,04	2,63	13,81	1,71

Equations used:

$$Gama\ n = \frac{Massa\ (Kg)}{Volume\ (L)}$$

$$Pi\ (g) = Peso\ Pi(g) - Cápsula\ (g)$$

$$Pf(g) = Peso\ Pf(g) - Cápsula\ (g)$$

$$Pa\ (g) = Pi\ (g) - Pf\ (g)$$

$$h(\%) = \left(\frac{Pa(g)}{Pf(g)}\right)x100$$

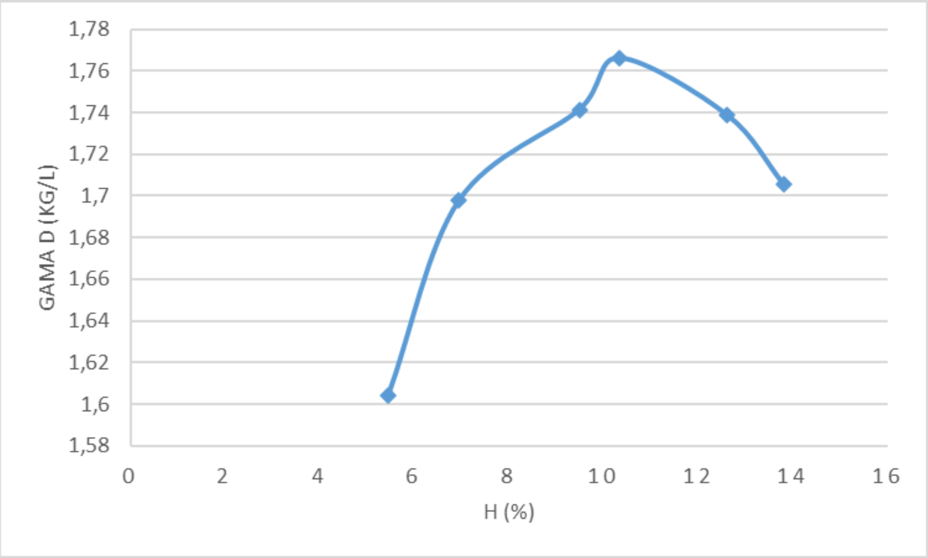
$$Gama\ d\left(\frac{Kg}{L}\right) = \left(\frac{Gama\ n\left(\frac{Kg}{L}\right)}{h(\%) + 100}\right)x100$$

Where:

- mass = value of the soil sample in the volume of the cylinder;
- volume = total volume of the large cylinder used in the test;
- Range n = natural specific gravity;
- Capsule = weight of capsule.
- Pi = weight of the soil plus water (in grams);
- Pf = weight of dry soil (in gram);
- Pa = weight of water (in grams);
- h = moisture content (in %);
- Range d = dry apparent specific weight (in Kg/L).

Based on the results presented in Table 2, a graph (Graph 1) was prepared that relates the dry apparent specific weight with the moisture, making it possible to find the value of the optimal soil moisture content, which was around 10.2%.

Graph 1. Soil compaction curve



Once the optimal soil moisture content was determined, the California Support Index tests were initiated, using a specimen with a diameter of 15.2 cm, compacted with a large Proctor in 5 layers with 12 equally distributed strokes.

Once the molding of the specimens was completed, the indicator clocks were installed and the specimens were immersed in a tank with water (Figure 7), as prescribed by NBR 9895:2017. The readings of the clocks were carried out during four consecutive days, with an interval of 24 hours, and it was possible to obtain values of soil expansion. Once the readings were completed, each specimen was removed from the water and allowed to flow for 15 min, as provided for in NBR 9895:2017, and then taken to the press for penetration testing.

Figure 5. Specimens submerged in a tank with water.

Source: The author

4.2 TESTING OF THE DIFFERENT BASE LAYER MIXTURES

Following the experimental program, a series of soil/RCC experiments was initiated to determine the best dosage for the base layer, which occurs with 60% CBR, i.e., 60% penetration resistance.

Figure 6 shows a specimen molded with one of the analyzed mixtures.

Figure 6. Molded soil mixture/RCC specimen.

Source: The author

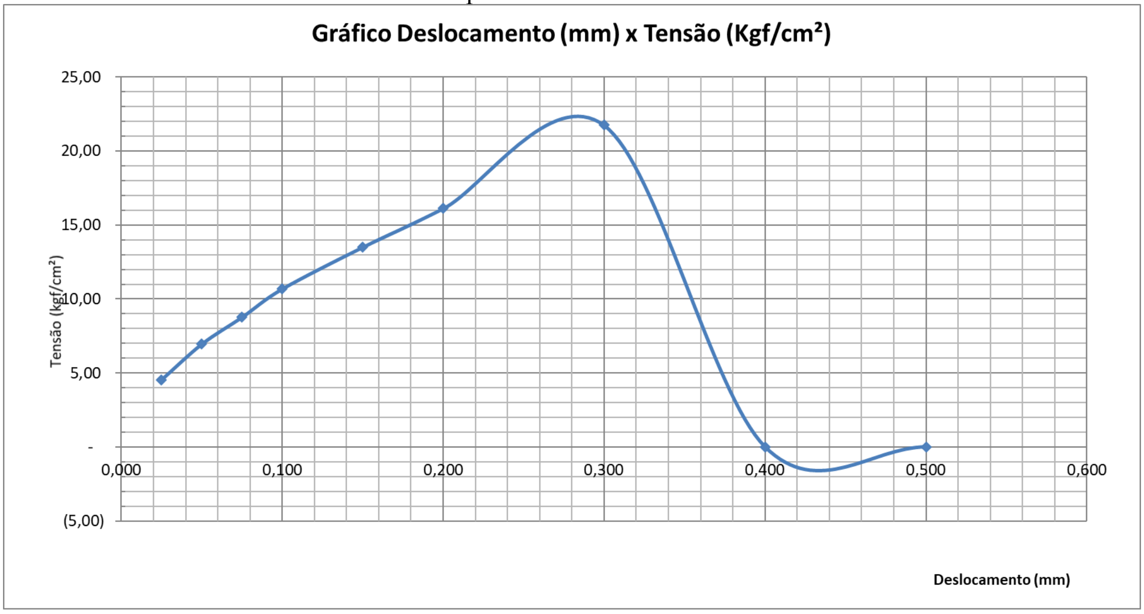
The results of stress x displacement are shown in Graphs 2 and 3, respectively for the soil sample and for the soil-RCC sample in the 60/40 percentage, i.e., the first mixture evaluated consisted of 40% RCC and 60% soil.

Analyzing the graphs, it can be said that the resistance to soil penetration was 15.2% and, when adding 40% of construction waste, the value of resistance to penetration rose to 21%. Despite the increase, the CBR result is still lower than expected. Thus, it was necessary to perform the same test for other soil-RCC mixtures, in order to achieve the CBR of 60%, as prescribed by standard.

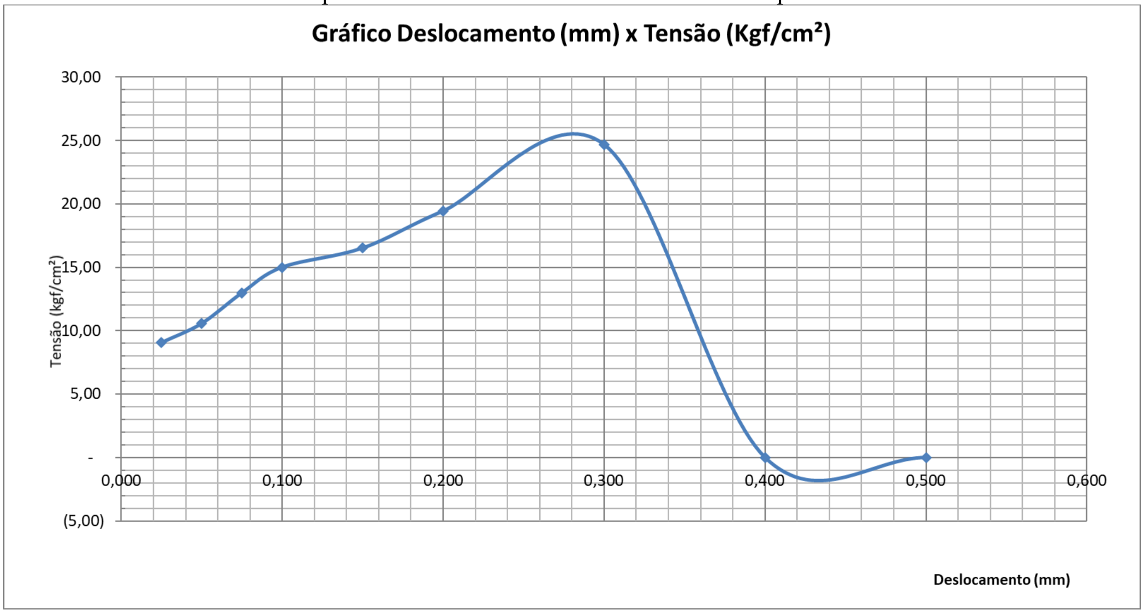
Probably, the amount of RCC in the mixture should be increased, since the possibility of the existence of fines in the mixture increases and, therefore, filling voids and increased compaction.

The expansion values, both of the soil and of the mixture, were below 0.5% (requirement of DNIT 141/2010-ES for the structural function of the base of a pavement), being 0.23% for the soil sample and 0.18% for the sample with 40% of RCC.

Graph 2. ISC from the soil.



Graph 3. ISC of the SOLO/RCC mix at 60/40 percent.

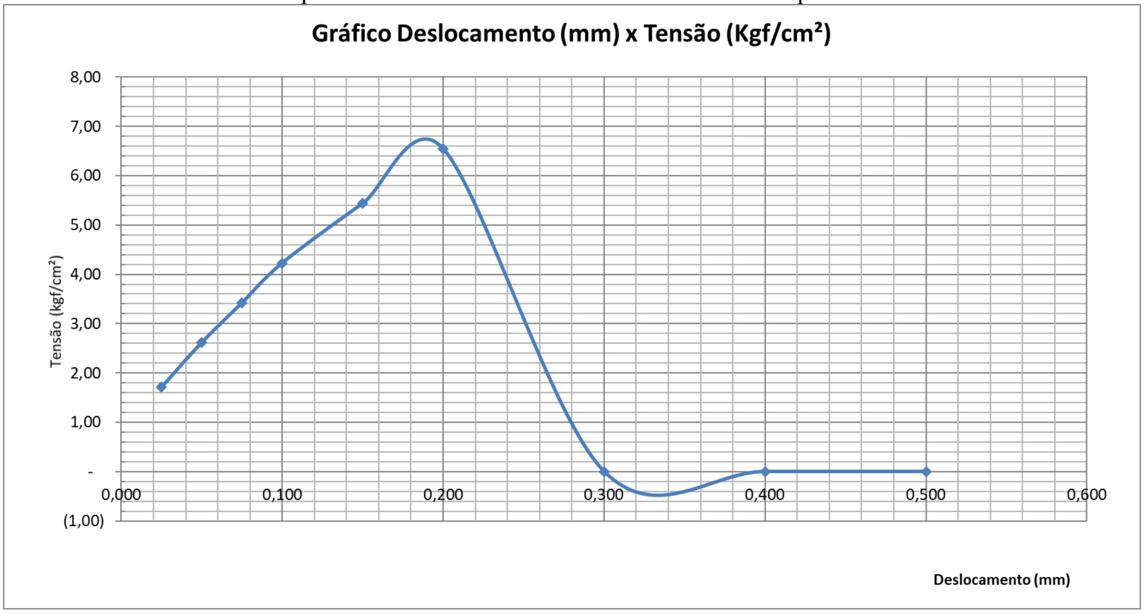


Graph 4 shows the stress x displacement results of the ISC test of the soil-RCC mixture in the 40/60 percentage, i.e., containing 60% of construction residue.

It is observed that when the percentage of RCC in the mixture increased, the SSI increased from 21% to 61.6%; significant increase and that meets the minimum value of 60% in the base layer, prescribed by DNIT 141/2010-ES.

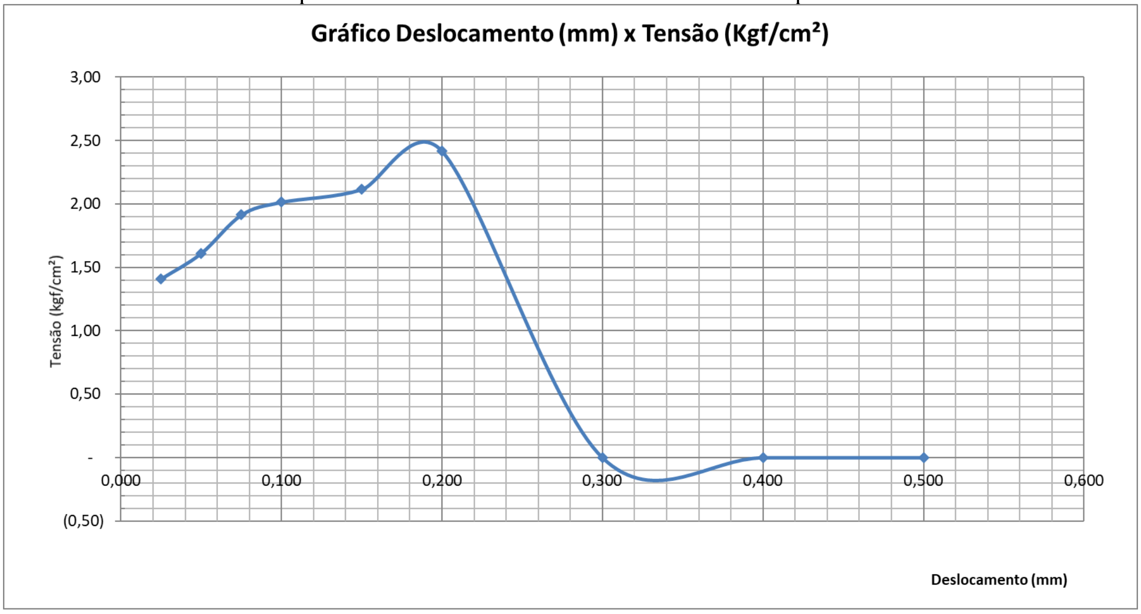
A probable explanation for the gain in the ISC by increasing the percentage of residue is the presence of fines that the residue has, which ends up filling the voids and increasing the compaction of the mixture.

Graph 4. ISC of the SOLO/RCC mixture at 40/60 percent.



The ISC of the mixture was also performed with 20% soil and 80% RCC, and it showed a significant drop in penetration resistance, going to the value of 15%, as shown in Graph 5. This drop is due to the low adhesion between the particles, which was caused by the low amount of soil, making the mixture unfeasible for the base layer.

Graph 5. ISC of the SOLO/RCC mixture at 20/80 percent.



The expansion values of the 40/60 and 20/80 mixtures were, respectively, 0.11% and 0.08%, also remaining below 0.5%.

Table 3 shows a summary of the mixtures studied. Therefore, it is concluded that the optimal mixture found was 60% of RCC and 40% of soil, reaching all normative parameters.

Table 3. SSI results obtained from the tested mixtures.

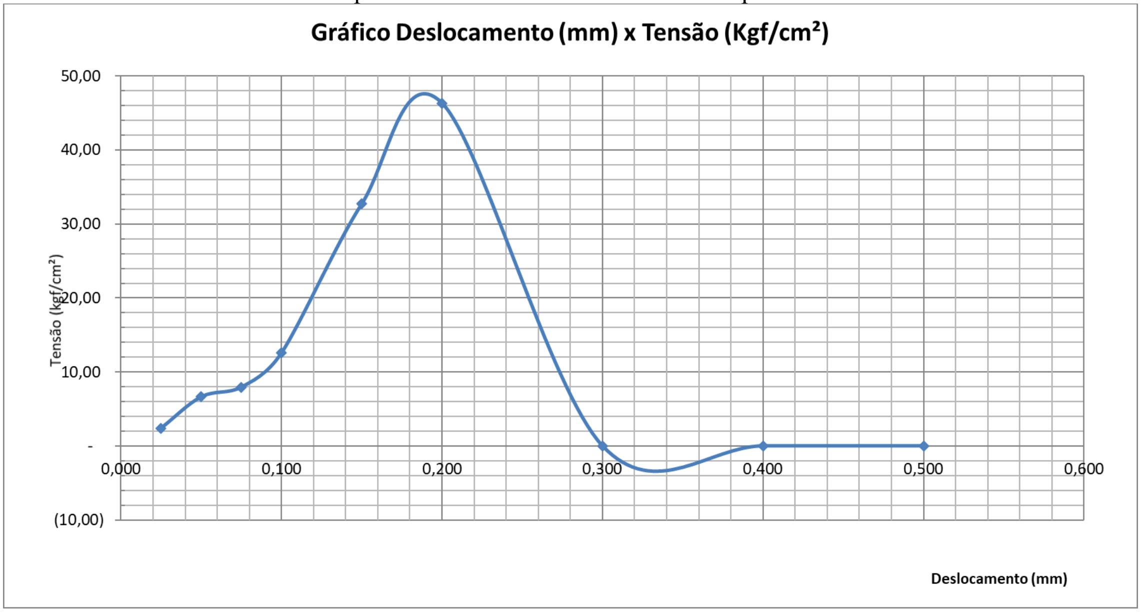
Amostras de Solo-RCC	Solo	RCC	ISC
Amostra 1	100%	0%	15,1%
Amostra 2	60%	40%	21%
Amostra 3	40%	60%	61,6%
Amostra 4	20%	80%	15%

4.3 BASE LAYER STUDY

From the results obtained throughout the work, it is evident that it is possible to totally replace the natural aggregate by the RCC aggregate in the base layer of highways, working on the composition of 40% of soil and 60% of construction waste, since all normative parameters are met, in addition to providing economic and environmental improvements.

For comparative purposes only, the SSI test was performed for the base layer with 50% gravel 1 and 50% soil. Graph 6 shows the ISC of the mixture. Using the natural aggregate, the ISC resulted in 71.1%, i.e., 15% higher than the mixture with waste, but without the economic and environmental attractions.

Graph 6. Mix ISCBrit to 1/soil at 50/50 percent.



4.4 COST COMPARISON ANALYSIS:

For the cost comparison, the DNIT Road Costs Manual of 2003, where, for the base layer, the order of 2.4 t/m³ is used as the total need for material to be used in the execution of 1 m3 of the service.

Thus, 1.2t of soil and 1.2t of gravel for the standard base layer, and 1.44t of RCC and 0.96t of soil for the base made with the optimal mixture found in this work.

The cost of the materials was based on the prices practiced in the region of Votuporanga-SP, which are: the m³ (1.6 t/m³) of soil is R$30.00, the m³ (1.5 t/m³) of gravel is R$120.00 and the m³ (1.5 t/m³) of RCC is R$23.00. Table 4 shows the quantities and costs spent in each of the situations.

Table 4. Cost Comparison Between Standard and RCC Base Tiers

	Solo (m³)	Brita (m³)	RCC (m³)	Custo total
Amostra Padrão	0,75	0,8	0	118,5
Amostra da Mistura	0,6	0	0,96	40,08

From dThe results shown in Table 3 show that the aggregate from civil construction waste provides a great economic advantage in relation to the natural aggregate, reaching a saving of 66% when applied in the base layer of the highway.

REFERENCES

ABRECON - Associação Brasileira para Reciclagem de Resíduos da Construção Civil e Demolição. Encontro nacional das usinas de reciclagem de RCD. 2021.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT. NBR 15.112/04 – Resíduos de construção e resíduos volumosos; Áreas de transbordo e triagem; Diretrizes para projeto, implantação e operação. Rio de Janeiro, 2004.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 15.113/04 – Resíduos sólidos da construção civil e resíduos inertes. Aterros; Diretrizes para projeto, implantação e operação. Rio de Janeiro, 2004.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 15.114/04 – Resíduos sólidos da construção civil. Áreas de reciclagem. Diretrizes para projeto, implantação e operação. Rio de Janeiro, 2004.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 15.115/04 – Agregados reciclados de resíduos sólidos da construção civil. Execução de camadas de pavimentação. Procedimentos. Rio de Janeiro, 2004.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 15.116/04 – Agregados reciclados de resíduos sólidos da construção civil – Utilização em pavimentação e preparo de concreto sem função estrutural. Rio de Janeiro, 2004.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 9895 – Solo- Método de ensaio- Índice de suporte Califórnia (ISC). Rio de Janeiro: ABNT, 2016.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 13292 – Solo- Determinação do coeficiente de permeabilidade de solos granulares à carga constante Rio de Janeiro: ABNT, 2021.

AZEVEDO, G. O. D., KIPERSTOK, A., MORAES L. R. S. Resíduos da construção civil em Salvador: os caminhos para uma gestão sustentável. Engenharia Sanitária e Ambiental, 2006; 11(1): 65-72, 2006.

BERNUCCI, Liedi B. et al. Pavimentação asfáltica: Formação básica para engenheiros. 504 f. PETROBRAS: ABEDA, Rio de Janeiro, 2006.

CARNEIRO, Alex P. et al. Reciclagem de Entulho para a produção de materiais de construção: Projeto Entulho Bom – Salvador: Editora UFBA, 142-186, 2001.

CONAMA (CONSELHO NACIONAL DO MEIO AMBIENTE). Resolução n° 307, de 5 de julho de 2002: Diretrizes, critérios e procedimentos para a gestão de resíduos da construção civil, julho, 2002.

DEPARTAMENTO NACIONAL DE INFRAESTRUTURA DE TRANSPORTES. DNIT. DNIT 139/2010 – Pavimentação: Sub-base estabilizada granulometricamente - Especificação de Serviço. Espirito Santo, 2010.

DEPARTAMENTO NACIONAL DE INFRAESTRUTURA DE TRANSPORTES. DNIT. DNIT 137/2010 – Pavimentação: Regularização do subleito - Especificação de Serviço. Espirito Santo, 2010.

DEPARTAMENTO NACIONAL DE INFRAESTRUTURA DE TRANSPORTES. DNIT. DNIT 141/2010 – Pavimentação: Base estabilizada granulometricamente - Especificação de Serviço. Espirito Santo, 2010.

DEPARTAMENTO NACIONAL DE INFRAESTRUTURA DE TRANSPORTES. DNIT. MANUAL DE CUSTOS RODOVIÁRIOS - VOLUME 4, 2003.

DEPARTAMENTO NACIONAL DE ESTRADAS E RODAGEM – DNER-ME. NORMA 133/94 - Misturas betuminosas: determinação do módulo de resiliência. Rio de Janeiro, 2009.

DEPARTAMENTO NACIONAL DE ESTRADAS E RODAGEM – DNER-ME. DNER-ME 049/94 – Solos: Determinação do Índice de Suporte Califórnia utilizando amostras não trabalhadas. Rio de Janeiro, 1994.

DEPARTAMENTO NACIONAL DE ESTRADAS E RODAGEM – DNER-ME. DNER-ME 82/94 – Solos: Determinação do Limite de Plasticidade. Rio de Janeiro, 1994;

DEPARTAMENTO NACIONAL DE ESTRADAS E RODAGEM – DNER-ME. DNER-ME 122/94 – Solos: Determinação do Limite de Liquidez; Método de referência e Método expedito. Rio de Janeiro, 1994.

GRUBBA, David C. R. P. Estudo do comportamento mecânico de um agregado reciclado de concreto para utilização na construção rodoviária. 163p. Dissertação – Universidade de São Paulo, São Carlos, 2009.

HANSEN, Torben C. Recycled of demolished concrete and masonry. 316p. London: Chapman & Hall, 1992.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. Sistema de Contas Nacionais Trimestrais - SCNT. Rio de Janeiro: IBGE. IBGE – Instituto Brasileiro de Geografia e Estatística, 2019.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. Banco de dados do IBGE.

PEREIRA, L. A. F.; AMORIM, E. F.; FREITAS NETO, O. (2022). Construction and demolition waste applied to road pavement layers: a systematic review. Research, Society and Development, 11(4), e28611426689. https://doi.org/10.33448/rsd-v11i4.26689.

PUPIM, F. H. Gerenciamento de resíduos sólidos urbanos na cidade de Votuporanga –SP. 2013. 57f. Trabalho de Conclusão de Curso - Curso Técnico em Edificações, Instituto Federal de Educação, Ciência e Tecnologia de São Paulo, Votuporanga, 2013.

ROZA, A. E. (2018). Contribuição para o projeto mecanístico-empírico de pavimentos asfálticos na região norte do estado do Mato Grosso. Dissertação (Mestrado) - Programa de Pós-Graduação em Engenharia Civil, Universidade Federal do Rio de Janeiro, Rio de Janeiro.

SANTOS, A. G; MATTE, G. R. Estudo da mistura de solo e agregado reciclado para construção de camadas de pavimentos de União do Oeste – SC. In: XXVIII Congresso de Pesquisa e Ensino em Transportes, 2014, Curitiba. ANPET 2014, 2014.

SOUZA, B. G. 2022. Permeable concrete pavement elaborated with civil construction residue. “Principies and concepts for development in nowadays society 1”. Editora Seven. Cap.70. P857-866. ISBN: 979-8-218-07792-1.

TAMURA, J. Y. Estudo sobre misturas solo-agregado reciclado de resíduos sólidos da construção civil, para fins de pavimentação de vias urbanas de baixo volume de tráfego. Pesquisa de Iniciação Científica da FAPESP - UNESP de Guaratinguetá. Guaratinguetá, 2012.

ZIMMER, A. S.; OMIDO, A. R. Avaliação do potencial de uso de resíduos da construção civil como agregado para base e sub-base de pavimento asfáltico. 20p. Dissertação Universidade Federal da Grande Dourados, Dourados, 2019.