

Evaluation of mixtures of lateritic clayey soil with quartzite and stone powder for road purposes

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ABSTRACT

This study evaluated the viability of using the fine residue of quartzite and stone powder from dunite mining in the southwest region of the State of Minas Gerais, Brazil, as aggregates mixed with Lateritic Clayey Soil for the treatment of base and sub-base layers of low-volume traffic pavement. Mixtures were prepared with soil and residues, in different proportions, tested in laboratory as proposed by MCT (Miniature, Compacted, Tropical) methodology for classification and to obtain some geotechnical properties. The results showed the potential replacement of conventional aggregate, since the samples evaluated were classified as “satisfactory” and/or “recommended” according to MCT, opening perspectives for a wider utilization of waste and by-products from quartzite slab production and ultrabasic rock aggregates.

RESUMO

Este trabalho tem por objetivo estudar a viabilidade de uso do resíduo fino de quartzito e do pó de pedra de dunite de minerações da região Sudoeste do estado de Minas Gerais – Brasil, como agregados misturados ao Solo de Comportamento Laterítico Argiloso (LG') no tratamento de camadas de base e sub-base de pavimentos de baixo volume de tráfego. Foram preparadas misturas com o solo e os resíduos em proporções distintas e realizados ensaios laboratoriais propostos na metodologia MCT (Miniatura, Compactado, Tropical) para classificação e obtenção de algumas propriedades geotécnicas. Os resultados alcançados apontam para a potencial substituição do agregado convencional, visto que as amostras avaliadas enquadraram-se nas classes “satisfatórias” e/ou “recomendadas” da Classificação MCT, abrindo perspectivas de um aproveitamento mais amplo dos resíduos e sub-produtos da produção de placas de quartzitos e agregados de rochas ultrabásicas.

1. INTRODUCTION

Rock mining, especially in the State of Minas Gerais, produces a large amount of tailings, due to the rudimentary process of extraction and exploration, resulting in considerable environmental liabilities. On the other hand, the increasing growth in the consumption of aggregates has motivated the development of studies aiming at the use of alternative materials, with lower cost, good quality and preferably sustainable, from the recycling of waste (Collares *et al.*, 2008a, 2008b; Francklin Junior, 2009; Francklin Junior *et al.*, 2010; Coladetti and Collares, 2015; Grilo, 2016).

In this context, the present study proposed to evaluate the technical feasibility of using the residues from the exploitation of foliated quartzite slabs and stone powder (derived from dunite

mining as a fine aggregate), replacing the traditional aggregate (sand), mixed with a Lateritic Clayey Soil (LG'), for use in the treatment of low-traffic pavement layers in the southwest region of the State of Minas Gerais. The study was carried out using the MCT methodology - Miniature, Compacted, Tropical (Nogami and Villibor, 2009) for classification and to obtain properties for checking the classification into the "satisfactory" and/or "recommended" areas.

The future implementation of the research results is expected to produce economic and environmental benefits. In relation to quartzite, whose waste represents about 90% of the extracted material, in addition to the environmental and economic benefits, with the availability of a low-cost product on the market, there will be a great social benefit for the region, since it will allow reintegration of employees who were fired for irregular mining activity, which were closed by environmental agencies or had their quarries exhausted.

As for stone powder, data obtained from a mining located in the municipality of Pratápolis, State of Minas Gerais, reveal that stone powder and crushing fines correspond to approximately 35% of the exploited material. Due to the difficulties in commercialization, this material accumulates in areas adjacent to the mine, which generates environmental impacts such as siltation of rivers and suppression of vegetation for new deposit areas.

2. LOW COST PAVEMENT AND THE MCT METHODOLOGY

Santana (1993) considers low-cost pavement to be the one that, in its construction, uses local and alternative materials, with regional technologies and experiences, seeking a minimum cost compared to traditional methods. Batalione *et al.*, (2010) explain that, in Brazil, low-cost pavement is related to fine sandy lateritic soil (SAFL), in the production of pavement structures with scarcity of granular material quarries and low to medium traffic volume. According to Villibor *et al.*, (2009), there are lateritic fine soils that do not have adequate characteristics for use as a base for pavements, but which, if mixed with each other or with sands, can behave similarly to SAFL soils.

According to Nogami and Villibor (1995), only the traditional study, with indices of consistency and grain size by sieving, did not demonstrate the qualities corresponding to the real performance of tropical soils. Therefore, the authors proposed a new classification of soils for road purposes called MCT - Miniature, Compacted, Tropical. In their research, they used lateritic clayey and sandy soils used in subgrade reinforcement layers and pavement sub-base. As a result, an excellent behavior was found, reaching high load-bearing capacity (CBR) for varieties of clay-sandy soils and clays. Therefore, in the late 1960s, lateritic soils were also adopted for the construction of bases on sections of highways and urban roads.

Nogami and Villibor (1995) also used on the base layer with local soils, thin coatings of sealed bituminous macadam, and surface treatments, reducing implementation costs. In 1970, the Highways Department of São Paulo State - DER applied the methodology in local roads, enabling the assessment of performance in situ. After a few years of using these tropical soils, a proprietary technology was developed, which, improved, resulted in the current MCT methodology developed by Nogami and Villibor, and since then it has been used by road agencies and city halls (Villibor *et al.*, 2009).

3. IMPACTS ON MINING AND ALTERNATIVE USE OF RESIDUES

Environmental degradation is an intrinsic factor of mining activity; thus, the concern with environmental management becomes very important. These projects have an exploration cycle

and, after that period, many facilities are abandoned without any process for restoring degraded areas (Tonidanvel, 2011). The impacts of mining companies are observed in the physical, biotic and anthropic environments, being negative and irreversible. The visual degradation is the most expressive, as there is the exposure of the rocky front of exploitation and the mining send-off creates a desert scenario, with an arid aspect. (Alecrim and Fabri, 2004).

The main negative impacts caused by mining are: stripping; biodiversity loss; contamination of soil, surface and groundwater; suppression of vegetation cover; noise and visual pollution; among others. On the other hand, there are positive impacts with the generation of jobs and taxes, improving the economic and social development in the region. However, the main concern is the future rehabilitation of the area, considering the environmental quality, safety and development of the surroundings (FEAM, 2011).

Currently, the generation of waste is the main challenge for industries that exploit quartzite, due to the low use of the extracted material, which leads to a series of problems such as: environmental degradation, low profit, less use of quarries in relation to the product/volume explored, difficulty in obtaining environmental certifications for export, logistics for waste disposal and closing the mine, since the current legislation holds the mining company responsible also after the end of production activities; however, justifying their maintenance, these quarries generate jobs, increasing the local economy (Russo, 2011; Alecrim *et al.*, 2006).

Bernucci *et al.*, (2010) emphasize the existence of alternative materials of increasing use in paving, resulting from reuse and recycling: blast furnace slag; aggregate from construction and demolition solid waste; waste from dimension stones exploitation, such as quartzite; asphalt mixture, among others.

Alecrim *et al.*, (2009) and Alecrim (2009) investigated the use of quartzite waste as material for pavements. For that, they analyzed soil-residue mixtures, in different proportions, with discontinuous particle size, according to Nogami and Villibor (1995) proposal, and continuous, according to traditional stabilization criteria. The proportions analyzed were 30%, 40% and 50% of soil and 70%, 60% and 50% of quartzite, respectively. Laboratory compaction, California Bearing Ratio and Resilient Modulus tests were performed. The results indicated that the grain size distribution of the aggregates has no significant influence on the mechanical properties of the mixtures and the values obtained were satisfactory for resistance and deformability, comparable to traditional granular materials and soil-aggregate mixtures. In conclusion, the studied waste is an alternative for use in sub-bases or flexible bases of pavements.

Collares *et al.*, (2012) evaluated the quartzite mining waste in the Southwest region of the State of Minas Gerais to check the possibility of recycling these materials as coarse aggregate in Portland cement concrete. In general, results were positive when compared to the conventional aggregate of gneiss, as well as the workability and properties in the hardened state; the compressive strength values ranged from 22.3 MPa to 24.4 MPa; tensile strength ranged from 1.98 MPa to 2.38 MPa; and the modulus of elasticity from 13.91 GPa to 16.54 GPa. The study showed a satisfactory behavior with the use of the waste, but it was necessary, to consider the site of collection of the material, since the traces of two samples, denominated A1 and A3, showed values lower than the gneiss trace (conventional), while the traces A2 and A4 presented an increase in the tensile strength in relation to the standard trace.

Reis (2016) and Reis *et al.*, (2018a, 2018b) sought alternatives to reduce the problems related to the disposal and reuse of mining waste, analyzed the technical feasibility of using

quartzite residue as coarse and fine aggregate for the production of Concrete Block Paving (CBP) to replace conventional aggregates, and obtained results that indicated the possibility of 100% replacement of coarse aggregate, since there were no differences in simple compressive strength in relation to conventional material. For the fine aggregate, washed and unwashed quartzite sand were used, and no significant differences were detected, with the difference of a better surface finish of the pieces for the unwashed material.

Russo (2011) studied applications for quartzite mining tailings from the *Serra da Canastra* region as aggregate. The samples were characterized physically, chemically and mineralogically. Tests were carried out for workability, compressive strength, degradation, abrasion, loss to shock and shape index in mortars. With the exception of the elongated dimensions of the coarse aggregate obtained, the results were positive, indicating the possibilities of using the waste for the production of precast concrete, industrialized mortars and pavements.

Grilo (2016) investigated the use of fine fraction of the quartzite mining tailings from the Southwestern region of Minas Gerais as fine aggregate in soil-residue mixtures with the local lateritic clayey soil to replace sand in the ALA (Sand Lateritic Clay with Sand) composition of the MCT methodology for pavement base in low traffic roads, comparing the performance of mixtures composed of quartzite residue in relation to mixtures with river washed sand, traditionally used. The values obtained in the tests, for example, in the Mini-CBR test, demonstrated the potentiality of using the fine aggregate of quartzite quartzite mining tailings as pavement base, presenting better results than with natural soil; in which soil-sand and soil-quartzite mixtures were analyzed in the proportions of 85% x 15%, 70% x 30% and 55% x 45%. Of these mixtures, those containing 30% and 45% residue were considered satisfactory for use as pavement base.

4. MATERIALS AND METHODS

Figure 1 shows the map with the location of the study area:

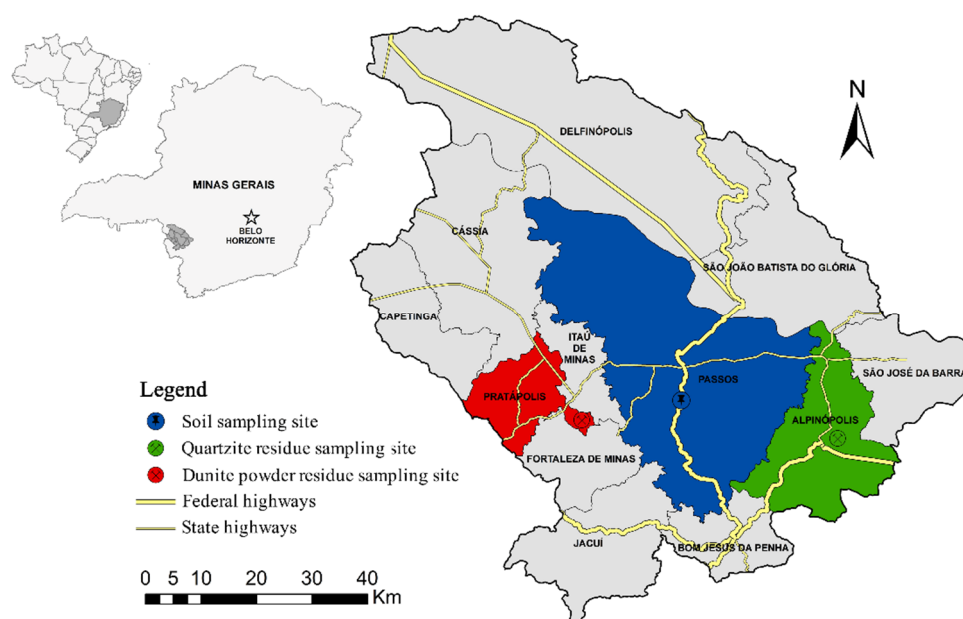


Figure 1. Location of the study area, the approximate distance between the sampling sites of the fine fraction of quartzite mining and stone powder (dunite) to the soil sampling sites were 52 km and 38 km, respectively

4.1. Sampling the materials

4.1.1. Soil

Soil was collected on the margins of the Domingo Ribeiro Resende Highway (BR-146), 4.5 km from Passos, State of Minas Gerais, towards Bom Jesus da Penha, State of Minas Gerais, at the coordinates 20°47'36.1" S and 46°36'23.8" W. To choose and define the sampling site, we used the previous studies carried out by Grilo (2016), who had already classified this soil as Lateritic Clay Soil (LG'), a soil very commonly found in the region of Passos, State of Minas Gerais. This soil was used as loan material during the paving of this highway. The collection was carried out based on the DNER-Pro 003 standard (DNER, 1994).

4.1.2. Sand

We used sand from a construction material deposit. Sand samples were acquired by Grilo (2016) and also used in this research. The soil-sand mixture was the comparison parameter for soil-residue mixtures.

4.1.3. Quartzite

The quartzite waste was collected in a mining located in the municipality of Alpinópolis, Southwest region of the State of Minas Gerais, on the *Chapadão Farm* (geographic coordinates 20°51'15.818" S and 46°21'11.390" W). Mining is carried out using surface mining, with explosives and excavators. The quartzite blocks are peeled and cut manually. The material used in this research was collected by Grilo (2016).

4.1.4. Stone powder (Dunite)

Dunite powder was collected in a quarry at *Morro Azul Mining* (geographic coordinates 20°49'29,237" S and 46°46'4,768" W), located in the municipality of Pratápolis, State of Minas Gerais, which represents the basal portion from the *Morro do Níquel* deposits, where lateritic nickel ore has been mined for some decades (Faria Júnior, 2011). At the site, a stripping of about 20m deep was carried out, which allowed the exposure of the rock mass, suitable for stone production.

4.2. Mixture Production: Lateritic Clayey Soil + Aggregates

To carry out the tests, the Lateritic Clayey Soil (LG') was mixed with the aggregates in different proportions, consisting of river washed sand, fine fraction of the quartzite mining and stone powder (dunite) residues, thus resulting in the following samples:

(S) Soil; (A) Sand; (Q) Quartzite and (D) Dunite.

S100 → 100% Lateritic Clayey Soil;

S70D30 → 70% Lateritic Clayey Soil + 30% dunite powder residue;

S60A40 → 60% Lateritic Clayey Soil + 40% river washed sand;

S60Q40 → 60% Lateritic Clayey Soil + 40% quartzite residue;

S60D40 → 60% Lateritic Clayey Soil + 40% dunite powder residue;

S50A50 → 50% Lateritic Clayey Soil + 50% river washed sand;

S50Q50 → 50% Lateritic Clayey Soil + 50% quartzite residue;

S50D50 → 50% Lateritic Clayey Soil + 50% dunite powder residue.

It should be noted that the mixture consisting of 70% soil and 30% aggregate was used only for stone powder (dunite), since this proportion with river washed sand and fine fraction of the quartzite mining tailings was previously studied by Grilo (2016).

4.3. Tests, characterization and classification of mixtures

4.3.1. Grain size analysis

The mixtures were subjected to readings of the symmetrical bulb hydrometer immersed in the solution containing the soil particles. The readings thus determined, together with data on the temperature of the solution during the test and data related to the calibration of the hydrometer used, comprised the database necessary for calculating the percentages of the particle sizes defined by the technical standard NBR 7181 (ABNT, 2018).

4.3.2. Proctor compaction test

The test was performed based on the NBR 7182 standard (ABNT, 2020). Samples were compacted at *Normal* energy, small rammers and cylindrical mold, in 3 layers, applying 26 blows in each one, in order to obtain the optimum water content and the dry density for each mixture.

4.3.3. Mini-MCV compaction test

The test was performed according to DNER-ME 258 (DNER, 1994). Samples were compacted, using a light weight rammer, with a sequence of increasing number of blows. From the test, we obtained a family of compaction curves and the empirical coefficients c' , which is the slope of the most inclined, straight portion of the sink curve, corresponding to the optimum water content that results in the Mini-MCV equal to 10, and d' , which is the slope of the most inclined straight portion of the dry branch of the compaction curve, corresponding to 12 blows on the graph.

4.3.4. Mass loss test by immersion in water

The test was performed according to DNER-ME 256 (DNER, 1994). After the Mini-MCV test, the compacted specimen was extracted, 10mm from its respective mold was submerged in water, horizontally. After 24 hours, the capsule with the detached mass was taken and the dry mass was determined. From this test, the P_i coefficient, expressed as a percentage, was calculated, which is the proportion of dry mass detached in relation to the extruded mass, using a correction factor depending on the type of detachment observed, aiming at the classification and prediction of surface stability of the soil to weathering.

With the results of these last two tests, samples were classified according to the MCT Classification of Tropical Soils (Nogami and Villibor, 1995).

5. RESULTS AND DISCUSSION

The results of the tests are presented below, following the order of the methodology used in the study.

Initially, Figure 2 illustrates the curves of the grain size composition of the samples. Table 1 lists their respective values. Figure 3 shows the Proctor compaction curves, and Table 2 presents the values of maximum dry density and optimum water content. Table 3 lists the values of the Mini-MCV, Mass Loss by Immersion and the MCT Classification.

Figure 4 shows the classification of the samples in the satisfactory or recommended areas, according to the Tropical Soil classification of Nogami and Villibor (1995).

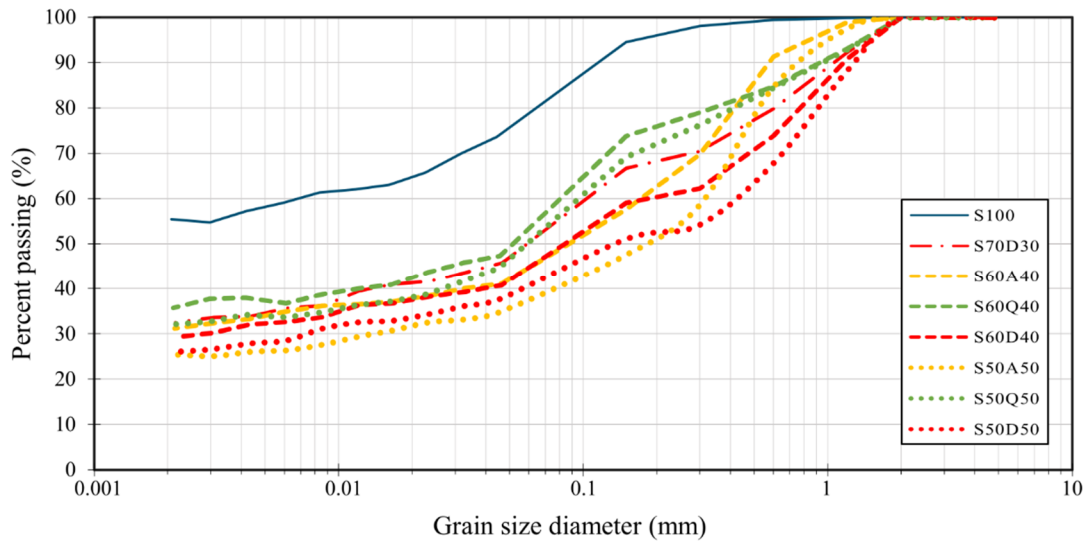


Figure 2. Grain size distribution curve of the samples

Table 1 – Grain size analysis of the samples

Sample	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
S100	55	24	21	0
S70D30	32	18	50	0
S60A40	31	14	55	0
S60Q40	35	18	47	0
S60D40	29	16	55	0
S50A50	26	12	62	0
S50Q50	32	18	50	0
S50D50	26	15	59	0

Table 2 – Proctor Compaction test of the samples

Sample	Optimum water content (%)	Maximum dry density (g/cm ³)
S100	26.60	1.51
S70D30	20.00	1.71
S60A40	19.50	1.73
S60Q40	19.10	1.73
S60D40	19.30	1.71
S50A50	15.60	1.81
S50Q50	18.70	1.74
S50D50	16.50	1.77

Table 3 – MCT Classification of the samples

Sample	c'	d'	Pi	e'	MCT Classification
S100	1.90	87.74	42	0.87	LG' – Lateritic Clayey
S70D30	1.40	245.0	42	0.79	LA' - Lateritic Sandy
S60A40	1.40	28.75	0	0.89	LA' - Lateritic Sandy
S60Q40	1.40	51.18	0	0.73	LA' - Lateritic Sandy
S60D40	1.40	63.88	12	0.76	LA' - Lateritic Sandy
S50A50	1.30	83.13	25	0.79	LA' - Lateritic Sandy
S50Q50	1.30	29.18	37.2	1.02	LA' - Lateritic Sandy
S50D50	1.40	101.67	18	0.72	LA' - Lateritic Sandy

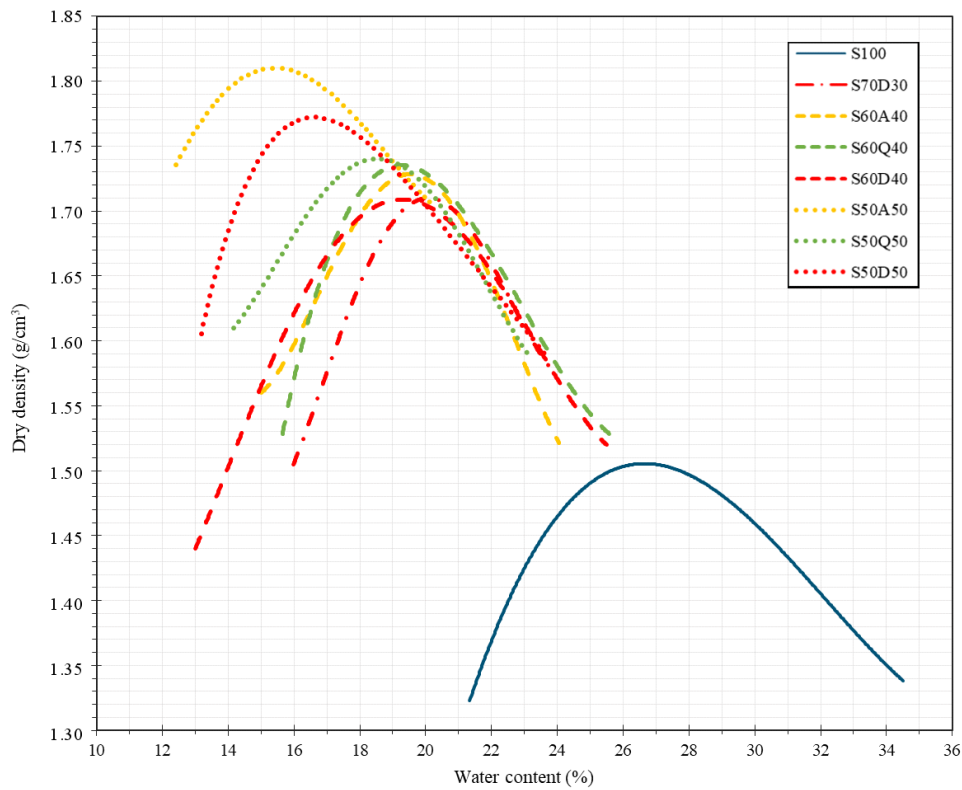


Figure 3. Proctor compaction curves of the samples

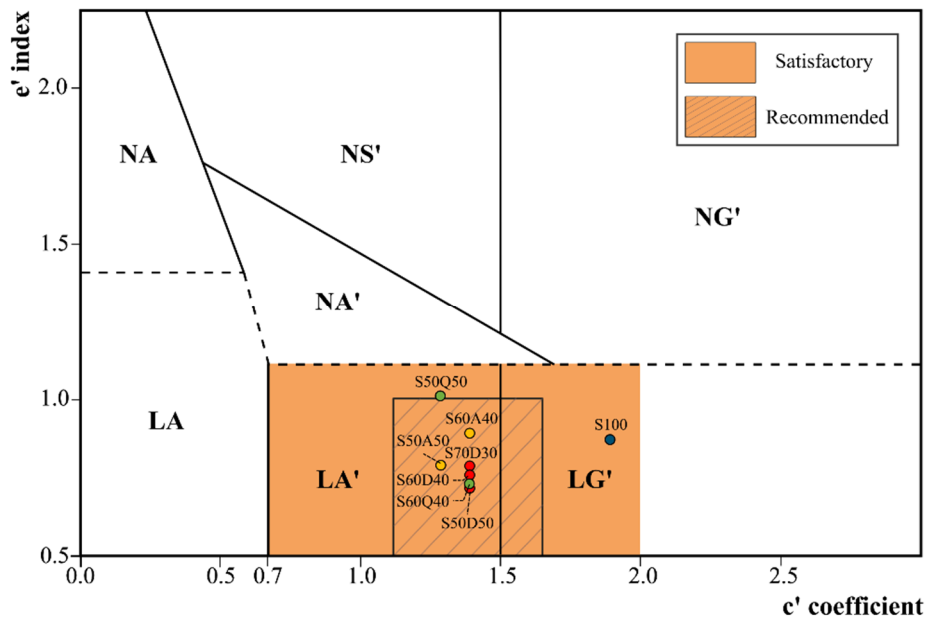


Figure 4. Location of mixtures in the MCT abacus Classification

The results were evaluated based on the MCT classification, since this is the most recommended in Brazil for low-cost paving (Nogami and Villibor, 2009). In this context, it was used the abacus classification of Nogami and Villibor (2009), which delimits areas suggesting “Recommended and Satisfactory” classification.

When plotting the results (Figure 4), it is observed that the natural soil, Lateritic Clayey (LG’), commonly found in the rural area of Passos, State of Minas Gerais, fits in the “Satisfactory” field

and may present geotechnical characteristics suitable for use in road base and sub-base, while mixtures, with the exception of the sample with 50% quartzite, fall into the “Recommended” field.

The mixture using 40% quartzite and all samples containing dunite powder mixed with the Lateritic Clay Soil (LG’) improved the material conditions, since it moved from the “satisfactory” material area to “Recommended” material in the MCT abacus classification (Nogami and Villibor, 2009);

Based on the results obtained in the Proctor compaction test (Table 2), the addition of sand (traditional aggregate), fine fraction of the quartzite mining tailings and dunite powder resulted in a reduction of the optimum water content and the increase in the apparent maximum dry density when compared to the parameters obtained for natural soil.

In view of these findings, it appears that the mixtures tested, with the exception of 50% quartzite, improved the conditions of the natural soil for use as base and sub-base, according to the criteria of Nogami and Villibor (2009).

6. CONCLUSION

- a) both fine fraction of the quartzite mining tailings and dunite powder, in appropriate proportions, considering the criteria presented by Nogami and Villibor (2009), can replace sand in mixtures with the Lateritic Clay Soil (LG’), for use in road base and sub-base layers, thus giving a proper destination to these materials that are commonly found in the mining send-off in the region;
- b) considering minimizing the impact and optimizing the use of materials discarded by mining operations, it is recommended to use the largest possible amount of these residues in the mixtures; therefore, the most recommended proportions among those studied in this study are: 60% soil + 40% quartzite and 50% soil + 50% dunite powder;
- c) additional studies, specific to the MCT Classification, as well as mechanical tests, especially the CBR and/or the Mini-CBR, recommended for base and sub-base of highways, should be conducted to confirm the effective use of these materials in the works.

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