# Study of Asphalt Binder Oil Residue and Municipal Solid Waste Ash to be Used in Low Traffic Pavements

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## Abstract

The great generation of urban solid has been a concern in several countries. This work presents a study with two materials: the asphalt binder oil residue accumulated in the bottom of asphalt tanks and the municipal solid waste ash, to be used, respectively, as a substitute of conventional binder in asphalt mixtures and for soil stabilization in pavements base layers. Were evaluated properties as the mechanical behavior of the mixtures through experimental tests. The results show the potential of incorporating these residues for low traffic roads, allowing the construction of low cost roads and an environmental use of the residue.

## Asphalt Binder Oil Residue

All operations in the petroleum industry generate a great number of oily residues. The refineries are responsible for most of such residues. Some products are accumulated in the bottom of the oil tanks. The residue studied is basically composed of emulsions of heavy oil, water and solids. Its variable composition, which is associated with the production in a refinery, makes it difficult to reuse the material. The residue studied was provided by the Refinery Lubnor/Petrobras, located in Fortaleza/Ceará, northeast Brazil. The generation of this type of residue varies in time and it also depends on the production capacity and generation of asphalt binder in the refineries. It is further associated with the maintenance of the storage tanks. The experience accumulated with this type of material is restricted to techniques of environmental treatment and use as a material in systems of waterproofing of sanitary embankments.

The aggregates were selected to fit gradation C of the Brazilian Federal Department of Roads (DNER). A coarse aggregate of maximum size of ¾" was used along with material passing sieve # 200, with real densities of 2.651 and 2.655, respectively. All aggregates are of granite origin, including the referred filler. Los Angeles Abrasion of the coarse aggregate was 49% DNER-ME 35 317/97. For the preparation of the laboratory mixture specimens, aggregates were sieved in all sieves between ¾" and #200 to assure the least variation of the target gradation curve.

The binder used in the study is an AC 50/70 refined at Lubnor/Petrobras. The residue known as asphalt binder oil residue results from the accumulation of material removed from the bottom of the storage tanks of conventional asphalt at the referred refinery. According to Magalhães (2006) the residue is considered of Class I (dangerous). Penetration tests, according to DNER ME-003/99 indicated that the residue's penetration is approximately 35% greater than the penetration of AC 50/70. Brookfield viscosity and the subsequent compaction and mixture temperatures were determined based on ASTM D 4402 (2002) and ASTM D 2493 (2001) at three different temperatures: 135, 150 and 175°C. The AC 50/70 presented higher viscosity than the oil residue (about 30-40% higher). The variation decreased with the increase in temperature. Mixing and compaction temperatures were approximately 10°C lower for the residue when compared to the conventional AC.

In Brazil, the AC optimum content in HMAs is typically determined using the Marshall Procedure NBR 12891/93 or local adaptations of the procedure. Five groups of three samples with different binder contents are prepared. A first content is based on the local design experience with the components used in the mixture. The other four contents are within ± 0.5% and within ± 1.0% of the first arbitrary content. The theoretical maximum density (TMD) was determined based on the Rice test ASTM D 2041(2000). The volumetric parameters used for selecting the binder content are: void in the mineral aggregate (VMA), volume of voids (Vv), bitumen-void ratio (BVR) and apparent density. The optimum binder content was determined from Vv and BVR, according to Soares et al. (2000). All of the samples presented volumetric parameters that satisfy the recommendations of DNER-ES 313/97 with respect to desired intervals of volume of voids (3-5%) and for the bitumen-void ratio (75-82%). The optimum binder contents found (Table 1) were a little above typical content for conventional mixtures using the same aggregates.

TABLE 1: Volumetric results of mixtures

| Mixture | 100% AC 50/70 | 100% Residue |
|---|---|---|
| Binder content (%) | 6.9 | 6.8 |
| VMA (%) | 19.5 | 19.1 |
| Vv (%) | 4.1 | 3.8 |
| BVR (%) | 79.1 | 79 |
| Apparent density | 2.29 | 2.30 |

| Mixture | 40% AC 50/70 + 60% Residue | 60% AC 50/70 + 40% Residue |
|---|---|---|
| Binder content (%) | 6.9 | 7.0 |
| VMA (%) | 19.6 | 19.7 |
| Vv (%) | 4.0 | 4.1 |
| BVR (%) | 79.4 | 79.3 |
| Apparent density | 2.29 | 2.29 |

Tensile strength tests in diametral compression (TS), at 0.8 mm/s, 25ºC, were performed according to DNER-ME 138/94. The stiffness parameter typically used in Brazil is the resilient modulus (RM) (Motta, 1995). The tests performed in the present research followed (DNER-ME 133/94). RM was determined in lab samples (diameter of 10 ± 0.02 cm and height of 6.35 ± 0.20 cm), at 25°C. Instantaneous and not total strain is considered in the determination of the RM. The results are presented in Table 2.

TABLE 2: Tensile strength and resilient modulus

| Mixture | (1) Tensile strength in diametral compression (Mpa) |
|---|---|
| 100% AC 50/70 | 0.85 |
| 100% Residue | 0.65 |
| 40% AC + 60% Residue | 0.78 |
| 60% AC + 40% Residue | 0.84 |

| Mixture | (2) Resilient Modulus (Mpa) |
|---|---|
| 100% AC 50/70 | 3,073 |
| 100% Residue | 2,232 |
| 40% AC + 60% Residue | 2,520 |
| 60% AC + 40 % Residue | 2,729 |

The tensile strength results for the mixture with 100% residue as the binder presented lower values when compared to the conventional HMA investigated. As for the resilient modulus, the results of the mixture with 100% residue are not far from results of conventional mixtures. Nevertheless, the RM value is approximately 27% lower when compared to the mixture with pure AC. The differences can be related to the lower viscosity of the residue when compared to the viscosity of the pure AC. In the binder formed by a mix of pure AC and residue, it is noted that the results are improved as the AC content increases in relation to the residue content, which is expected.

Mixture fatigue is typically obtained under diametral compression. The mixture with the residue as the binder presents the lower fatigue life, when considering the same stress state. The mixture with the pure AC and the one with 60% AC + 40% residue preformed very similarly, especially under lower stress states (Figure 1). The results indicate that a mixture with 100% residue should not be used under high traffic volumes but may be used for low traffic roads. Whereas a combination of AC and residue allows the use of a substantial amount of residue (40%) even for high traffic volume roads. Such percentage of residue represents an economy of approximately US$ 8,000/km.

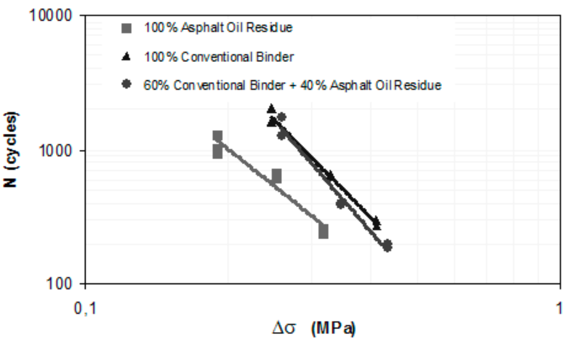


**Fig.1** Fatigue results.

## Municipal Solid Waste Ash

The use of alternative materials is not common practice in geotechnical engineering. Recent research has been conducted, aimed at this goal. It is not always possible to find natural soils that meet the requirements of the specifications for the use of stabilized bases and sub-bases without granulometric mixture. The soil, when found, is located far from infrastructure, which increases the costs for transportation. An alternative to minimize the high costs is stabilizing the soil with waste. The proposition of this study should be preceded by a prior knowledge of the potential and limitations of the regional materials.

This study evaluates the application of fly ash obtained from incineration of Municipal Solid Waste (MSW) use in base layers of pavements, by mixing the ashes with a non-lateritic regional clay soil. The Usina Verde is a privately held company located in the Federal University of Rio de Janeiro, and aims to provide environmental solutions for the disposal of municipal solid waste, through incineration with energy co-generation. The Usina Verde receives, daily, 30 tons of MSW Company's Waste Disposal of Rio de Janeiro. In sorting, recyclable materials are segregated manually and with metal detectors. Then the MSW is crushed and separate fine material and sent to drying. These wastes are sent to the incinerator, which operates at a temperature of 950ºC.

During the combustion process, two ashes are produced: bottom ash and fly ash. The bottom ash is deposited in the bottom of the chamber after combustion, referred to the storage tank and arranged into buckets. The hot gases and fly ash are exhausted chamber afterburner and inhaled into the recovery boiler, which is used to produce energy. Subsequently, the gases are neutralized in a set of washers and then the clean gases are extracted and discharged into the atmosphere. The wash solution is collected in settling tanks where the neutralization takes place with the ashes of the process and calcium hydroxide, which causes mineralization and this solution, is reused in the washing process. Then, the ash is sent to settling tanks where it is periodically removed and stored in buckets.

At the end of the incineration process are obtained from 8 to 10% by volume of the two ashes, which represent about 80% of bottom ash and 20% of fly ash (Fontes, 2008).

Fly ash is an effective agent for chemical stabilization in soil mechanics, changing the soil density, moisture content, plasticity and resistance of soils. Typical applications include: stabilization of soils to increase the strength, drying the soil and control of the contraction-expansion (ACAA, 2003).

The non-lateritic clay soil in study came from a deposit located in the city of Campo Grande/RJ. Fly ash comes from the burning of municipal solid waste (MSW) at Usina Verde, which is located on Rio de Janeiro/RJ.

The main chemical components of soil, which are normally found in residual soils, are SiO2, Al2O3 and Fe2O3, which participates actively in the process of chemical stabilization of soil (Rezende, 1999). These components were also obtained by Nascimento (2005), for three non-lateritic clays and Brant (2005) for three residual soils of basalts. The soil and MSW fly ash chemical composition can be observed on Figures 2 and 3.

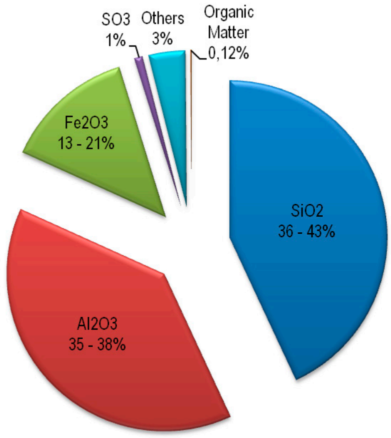


**Fig.2** Soil chemical composition.

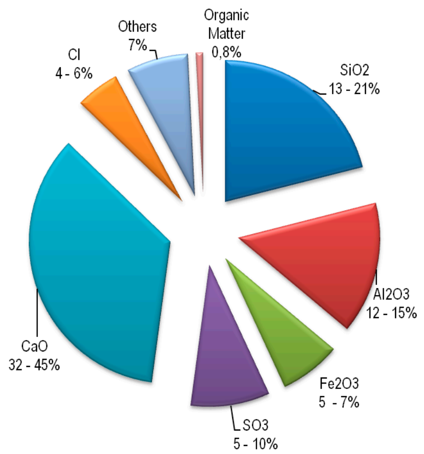


**Fig.3** MSW fly ash chemical composition.

It is notable the variability of the chemical composition of fly ash. It is noteworthy that the chemical composition of MSW fly ash under study is similar to that typical of fly ash from lignite coal mentioned by Winterkorn (1990), which has cementing properties. The geomechanical behavior of soils stabilized with MSW fly ash and fly ash from lignite coal can be compared.

Regarding the characterization of soil, MSW fly ash and mixtures can be noted as follows: first, the limits of Attemberg for pure MSW fly ash could not be performed due to the behavior of granular material, which during the test did not show plastic characteristics to their achievement. Second, that the inclusion of MSW fly ash decreases the liquid limit and plasticity index, and increases the plastic limit of soil. These results are comparable to the study by Bin-Shafique (2009), in which the addition of coal fly ash reduced the plasticity index of an expansive soil and a soft soil, both soils from Texas, USA. Nalbantoglu (2004) tested a coal fly ash to assess its stabilizing effect on two expansive soils on the island of Cyprus. In his study was found that the fly ash decreased the plasticity index of soils with highly plastic, but has less influence on the plasticity index of soils of low plasticity.

Regarding the classification MCT (Nogami and Villibor, 1995), the soil is classified as NG' behavior "non-lateritic-clay." These soils when compacted under the conditions of optimum moisture content and density maximum energy normal characteristics of the traditional very plastic clays and expansive. The use of these soils is related to restrictions resulting from its high expansibility, plasticity, compressibility and contraction when subjected to drying, its use is not recommended for base pavements, and some of the worst soil for the purpose of paving, from the tropical soils (Nogami and Villibor, 1995).

Curves of soil compaction and mixtures with fly ash obtained from the Modified Proctor tests, it can be stated that by increasing the level of ash in the mixture, the maximum dry density tends to decrease, which is consistent with research by Nicholson (2003), on the use of coal ash to stabilize tropical soils. Can be observed that the optimum moisture content decreases a level of 20% fly ash and grows to a maximum of 40%.

The results of Resilient Modulus tests (Figures 4 and 5) show that the Resilient Modulus of soil in study is dependent on the deviator stress and even adding the MSW fly ash, this behavior does not change. It is appreciated that the higher the deviator stress, the lower the value of resilient modulus.

The mixture with 20% MSW fly ash improved the mechanical behavior of pure soil, the mixture with 40% MSW fly ash downgrade the mechanical behavior, but it improved with cure time (Figure 6). Other influence factor is the cycle number of cycling load (Figure 7). The resilient modulus improved with cycling loading.

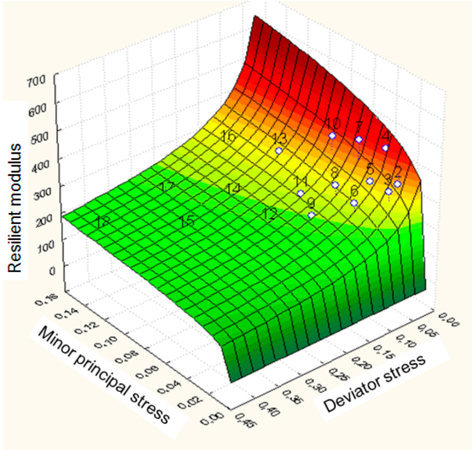

**Fig.4** Soil resilient modulus vs. stresses.

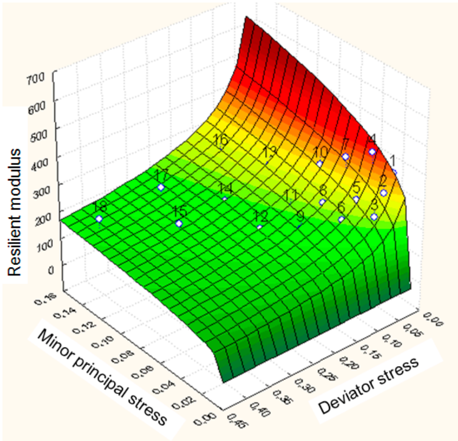

**Fig.5** Soil with 40% of MSW fly ash resilient modulus vs. stresses (with 7 days of cure).

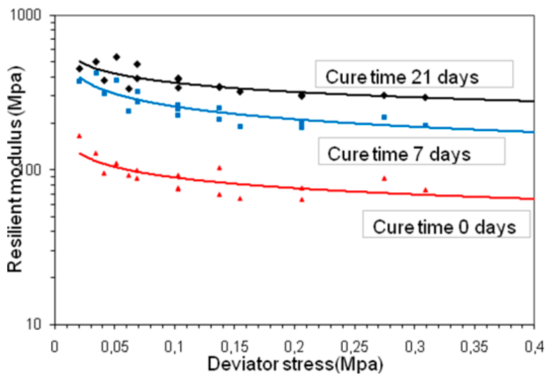

**Fig.6** Resilient modulus vs. stress of soil with 40% of MSW fly ash. – cure time variation.

The MSW fly ash decreases the expansion of the material (Figure 8), however, high content of fly ash when can deteriorate the mechanical behavior, resulting in a thicker layer.

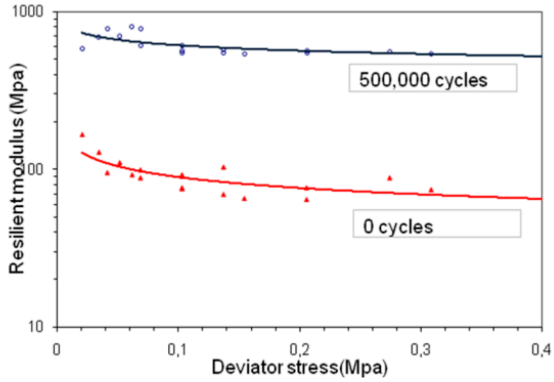

**Fig.7** Resilient modulus vs. stress of soil stabilized with 40% of MSW fly ash - cycles number variation.

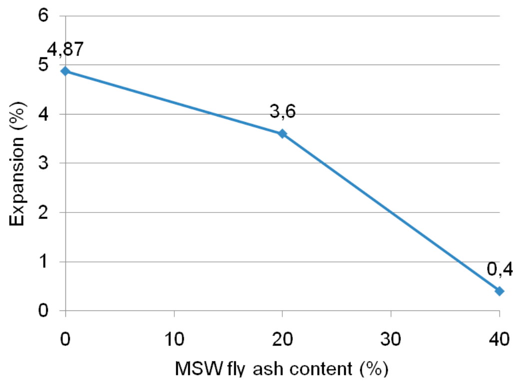

**Fig.8** Expansibility of soil stabilized with MSW fly ash.

Lixiviation and Solubility tests performed according to Brazilian standards NBR 10005 (ABNT, 2004b) and NBR 10006 (ABNT, 2004c) for MSW fly ash and soil stabilized with 40% fly ash content. The mixture is classified Non-dangerous and non-inert (Vizcarra, 2010).

The behavior of mixtures with MSW fly ash should be carefully evaluated for various MSW fly ash content, analyzing the results of physical, chemical, environmental, and mechanical together.

## Conclusions

- It was possible to produce a mixture with a mechanical behavior similar to a conventional HMA, specifically with 60% AC + 40% asphalt binder residue. The results indicate that a mixture with 100% of asphalt binder oil residue can be used in low traffic volume roads. Either combined or by itself in low traffic roads, the use of the residue represents not only great cost economy, but also an environmentally friendly solution for a current problem of the petroleum industry;

- Mixtures with MSW ash inclusion had a mechanical behavior compatible with the requirements for a low traffic volume. The inclusion of 20% of fly ash on the non-lateritic clay soil improved the mechanical behavior and reduced the expansion of the soil. The soil mixed with a content of 40% of fly ash worsened the mechanical behavior compared to pure soil, with the consequent increase in thickness; however, improved with cure time and cycle loading number, decrease significantly the expansion of the soil. The results were satisfactory, being dependent on the ash content added, cure time and cycle loading number, highlighting the positive work of MSW fly ash for use in base layers of road pavements, eliminating the current problems of waste disposal in dumps and landfills, putting a noble application to this material.

## Acknowledgements

The authors thank CNPq (MCT/CNPq 14/2009 # 480748/2009-8 project) and CAPES for the financial support, as well as *Lubnor/Petrobras* for the supply of the AC and the asphalt binder oil residue and *Usina Verde S.A.* for the Municipal Solid Waste ash supply.

## References

AASHTO (1996) TP46-94 - *Standard Test Method for Determining the Resilient Modulus of Soils and Aggregate Materials.* American Association of State Highway and Transportation Officials, Washington, D.C.

ASTM (2000) D 2041 – *Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixture.* American Society for Testing and Materials.

ASTM (2001) D 2493 - *Standard Viscosity-Temperature Chart for Asphalts*. American Society for Testing and Materials. American Society for Testing and Materials.

ASTM (2002) D 4402 - *Standard Test Method for Viscosity Determinations of Unfilled Asphalts Using the Brookfield Thermosel Apparatus.* American Society for Testing and Materials.

ABNT (1984) NBR 6459 - *Determinação do Limite de Liquidez.* Associação Brasileira de Normas Técnicas. Rio de Janeiro, Brasil.

ABNT (1984) NBR 7181 - *Análise Granulométrica.* Associação Brasileira de Normas Técnicas. Rio de Janeiro, Brasil.

ABNT (1986) NBR 7182 - *Ensaio de Compactação.* Associação Brasileira de Normas Técnicas. Rio de Janeiro, Brasil.

ABNT (1993) NBR 12891 – *Dosagem de Misturas Betuminosas pelo Método Marshall*. Associação Brasileira de Normas Técnicas. Rio de Janeiro, Brasil.

ABNT (1994) NBR 7180 - *Determinação do Limite de Plasticidade.* Associação Brasileira de Normas Técnicas. Rio de Janeiro, Brasil.

ABNT (2004a) NBR 10004 - *Resíduos Sólidos – Classificação.* Rio de Janeiro, 2004.

ABNT (2004b) NBR 10005 - *Lixiviação de Resíduos – Procedimento.* Rio de Janeiro, 2004.

ABNT (2004c) NBR 10006: *Solubilização de Resíduos – Procedimento.* Rio de Janeiro, 2004.

AMERICAN COAL ASH ASSOCIATION (ACAA). (2003) *Fly Ash Facts for Highway Engineers*. 4 Edition.

Bin-Shafique, S., Kahman, K., Yaykiran, M., Azfar, I. (2009) The Long-term performance of two fly ash stabilized fin-grained soil subbases. *Resources, Conservation and Recycling.*

Brant, Fábio de Albuquerque Caldeira (2005) *Propriedades físicas, químicas, mineralógicas e mecânicas de um perfil de solo residual basáltico localizado em um corte da Ferrovia Norte-Sul, no estado de Tocantins.* M.Sc. Disssertation. Civil Engineering Department of Pontifical Catholic University of Rio de Janeiro, PUC-Rio, Brazil.

DNER (1994) Departamento Nacional de Estradas de Rodagem. DNER-ME 093/94. *Solos – Determinação da densidade real.* Norma Rodoviária, Método de Ensaio.

DNER (1994) Departamento Nacional de Estradas de Rodagem. DNER-ME 131/94. *Solos – Determinação do Módulo de Resiliência.*

Norma Rodoviária, Método de Ensaio.

DNER (1994) *Métodos de Ensaios - Determinação do Módulo de Resiliência de Misturas Betuminosas.* DNER-ME 133/94. Ministério dos Transportes, Brasil.

DNER (1994) *Métodos de Ensaios – Misturas Betuminosas – determinação da resistência à tração por compressão diametral*. DNER-ME 138/94. Ministério dos Transportes, Brasil.

DNER (1997) *Pavimentação – Concreto Betuminoso.* DNER-ES 313/97. Ministério dos Transportes, Brasil.

DNER (1997) *Agregados – Determinação da abrasão "Los Angeles".* DNER-ME 35 317/97. Ministério dos Transportes, Brasil.

DNER (1999*) Material Betuminoso – Determinação da Penetração. DNER ME-003/99.* Ministério dos Transportes, Brasil.

Fontes, C. M. A. (2008) *Utilização das cinzas de lodo de esgoto e de resíduo sólido urbano em concretos de alto desempenho.* PhD. Thesis. Federal University of Rio de Janeiro, Brazil.

Magalhães, S. C. (2006) *Plano de gerenciamento de resíduos sólidos para a indústria de petróleo: o caso de Petrobras/Lubnor-CE.* M.Sc. Disssertation. Federal University of Ceara, Fortaleza, Brazil.

Medina, J., Motta, L. M. G. (2005) *Mecânica dos Pavimentos.* 2ª Edição. Editora UFRJ. Rio de Janeiro. Brasil. 570 p.

Motta, L. M. G. (1995) *Curva de Resiliência e Fadiga de Misturas Asfálticas.* Instituto Brasileiro de Petróleo, São Paulo, SP, Brasil.

Nalbantoglu, Z. (2004) Effectiviness of Class C fly ash as an expansive soil stabilizer. *Construction and Building Materials.* Vol. 18, p. 377-381.

Nascimento, R.R. (2005) *Utilização de agregados de argila calcinada em pavimentação: uma alternativa para o estado do Acre.* MSc. Dissertation. Federal University of Rio de Janeiro, Brazil.

Nicholson, P.G. (2003) Fly Stabilization of Tropical Hawaiian Soils. *Fly Ash for soil improvement*. ASCE.

Nogami, J. S., Villibor, D. F. (1995) *Pavimentos de Baixo Custo com Solos Lateríticos*, Editora Villibor, São Paulo. 240 p.

Rezende, L.R. (1999) *Técnicas Alternativas para a Construção de Bases de Pavimentos Rodoviários.* MSc. Dissertation. Federal University of Brasilia, Brazil.

Soares, J.B.; L.M. Motta; J.A. Paiva e J.V.C. Branco (2000) *Propriedades Mecânicas de Misturas Asfálticas com Variação de Granulometria e de CAP.* 15º Encontro de Asfalto - IBP.

Vizcarra, G.O.C. (2010) *Aplicabilidade de Cinzas de Resíduo Sólido Urbano Para Base de Pavimentos.* M.Sc. Disssertation. Civil Engineering Department of Pontifical Catholic University of Rio de Janeiro, PUC-Rio, Brazil.

Winterkorn, H. F., Pamukcu, S. (1990) Soil Stabilization and Grouting. *Foundation Engineering Handbook* editado por Fang, Hsai-Yang, 2. ed., p. 317-348.