Evaluation of the use of steel slag in microsurfacing

Pedro B. de Castro[1], Bruno T. A. da Silva[2], Suelly H. de A. Barroso[3]
([1] National Department of Transport - Brazil，[1]pedrodcastro@yahoo.com.br, Brazil)

([2 e 3] Laboratório de Mecânica dos Pavimentos da Universidade Federal do Ceará,
Campus do Pici s/n, Bloco 703, Departamento de Engenharia de Transportes,
CEP 60440-554, Fortaleza-CE, Brazil）([2]brunoangelo@ufersa.edu.br e [3]suelly@det.ufc.br)

ABSTRACT

Microsurfacing is a type of bituminous coating applied in pavement in order to prevent and maintain it. Microsurfacing has succesfully been used in states of Brazil and also in many countries all over the world. Local aggregates used for microsurfacing composition are in some cases scarce and expensive. This situation has motivated researchers to study new materials to be used concerning bituminous wearing course. Therefore, the main objective of the present research is to verify the technical, economic and environmental viability of using steel slag in microsurfacing applications. To reach the main objective, a laboratory procedure was developed in four steps. In the first step, the collection and characterization of conventional and alternative aggregate (steel slag) and polymer-modified emulsified asphalt were made. In the second step, mix project, surface abrasion resistance and set time tests were performed. In the third step, the microsurfacing performance was analyzed by a laboratory traffic simulator. In the fourth step, a comparative study of costs concerning microsurfacing application using conventional and alternative aggregates were performed. The laboratory procedure results indicated that the alternative aggregate studied has the potential to be used in microsurfacing aplications with high quality and cost reduction.

Keywords: Pavement, Microsurfacing, Steel Slag, Laboratory Traffic Simulator

1. INTRODUCTION

Microsurfacing (MS) is one of the techniques applied to preventive maintenance of asphaltic pavements, with good results when used in heavy traffic highways (ABEDA, [1]). The MS is composed of 90-95% of aggregates. In recent years, there has been a decrease in the supply of aggregates in some Brazilian states, but on the other hand, there is availability of several residues that can be better investigated to be used in the paving area in order to promote the preservation of the environment.

According to Loiola [2], certain types of alternative aggregates have been applied to paving. One of the materials with potential to be employed, in substitution of the mineral aggregate, is the Steel Aggregate (SA). Although the use of SA has already been carried out in the pavement area since the 1990s, both in granular and asphalt layers, studies that analyze the behavior of SA in MS applications are still incipient in Brazil. This paper studied, the use of SA as an alternative aggregate in MS, with analysis concerning its technical, economic and environmental feasibility.

Several MS studies have been developed, addressing fundamental aspects of dosage, implementation, application of effective benchmarking and comparison to other maintenance techniques. The studies of Santo and Reis [3], Vale [4], Vale and Suzuki [5], Reis [6], ABEDA [1], Castro [7] e Ceratti and Reis [8] can be highlighted in Brazil Regarding the international literature the studies on microsurfacing are well established, among which can be mentioned FHWA [9], Hick *et al*. [10], Austroads [11], Hein *et al*. [12], CALTRANS [13], Broughton *et al.* [14], Ulhman [15], NCHRP [16], ISSA A-143 [17], Apparoa *et al.* [18], Ji *et al.* [19], Bae and Stoffels [20].

SA is a product that has been gaining prominence in the pavement area, since its use has been well researched for road purposes. However, SA has in the presence of oxides such as CaO and MgO in its composition. These oxides have an expansive feature due to chemical reactions. Care should be taken to check whether the AS is already cured before being applied to road works.

Over the years, several works were developed in order to make the use of SA in road works feasible. In Brazil, there is record of the first use of this residue in the paving in 1986, in the state of Espírito Santo, where the SA was used over a stretch of more than 100 km (Silva e Mendonça, [21]). Other authors that studied the use of SA in granular layers were Rohde [22] Parente *et al*. [23], Santos Neto [24] and Cavalcante *et al.* [25]. In addition, DNIT [26] also studied SA as an aggregate in base and sub-base layers. The use of SA in hot-machined asphalt mixtures was also investigated and the results showed that it has the potential to replace the conventional aggregate in such blends as can be seen in Castelo Branco [27], Pedrosa [28], Silva [29] and Tavares [30].

In Brazil, the use of SA for thinner coating type Surface Treatment (ST) is more recent, dating from 2007, and started by Loiola [2] and Pereira [31]. The results showed that the SA also had a satisfactory performance and an experimental pavement section was built as reported by Rocha [32].

Recently, Vasconcelos *et al*. [33] evaluated the behavior of Double Surface Treatment (DST) and Cape Seal, having performed a comparison using SA and conventional aggregates. However, its use in MS has been insufficiently researched, this is why studies should be more developed in order to verify if this type of technique, the SA will also perform well.

2. MATERIALS AND METHODS

For the execution of the experimental program, a Mineral Aggregate (MA), considered of excellent behavior for application in MS, and a Steel Aggregate (SA) were collected. The experimental program was divided into the following steps: (i) characterization of materials; (ii) dosing of the specimens; (iii) evaluation of the coating behavior with the use of an LCPC type laboratory traffic simulator and (iv) economic analysis of the studied aggregates.

The characterization tests carried out, including those specific for the steel aggregates were: Granulometry (DNER-ME 083/98); Form index (DNER-ME 086/94); Los Angeles Abrasion (DNER-ME 035/98); Methylene blue (NBR 14949/2003); Sand equivalent (DNER - ME 054/94). To complement the SA characterization, the environmental tests of solubilization (NBR 10006/2004) and leaching (NBR 10005/2004), as well as the evaluation of its expansion (DNIT - ME 113/2009) were necessary.

The asphalt emulsion used in the study was CCS-1P (Cationic Controlled Setting Polymer Modified) and was characterized by the following tests: Saybolt Furol Viscosity (NBR 14491/2000); Sedimentation (DNER - ME 006/2000); Screening (NBR 14393/99); Particle load (NBR 6567/2000); Residue by evaporation (NBR 14376/2007); Determination of pH (NBR 6299/99); Penetration (DNER - ME 003/99); Elastic recovery (DNER - ME 382/99) and Softening point (NBR 6560/2008).

In order to perform the dosage of the test specimens, the Wet Abrasion Test (NBR 14746/2001) was performed, as well as sand adhesion test by the Loaded Wheel Tester (LWT) (NBR 14841/2002), determination test of the MS curing characteristics by determining the cohesion of the mixture (NBR 14798/2002), the minimum mixing time determination test (NBR 14758/2001) and the mixture adhesion determination test (NBR 14757/2001). The behavior of the MS in the laboratory was measured by analyzing the surface wear (NBR 14746/2001) and the cure time for the traffic release (NBR 14798/2002) of MS test bodies molded at the optimum design level.

This work also evaluated the behavior of the MRAF under the action of the small traffic simulator following the guidelines of the French standard NF P98-253-1 (AFNOR, 1991). In order to eliminate variables that could interfere in the analysis of the obtained results, it was chosen to use the methodology developed by Vasconcelos [33] as shown in Figure 1. The aspects observed in the simulator test were: accumulated permanent deformation, surface wear, microtexture and macrotexture. The macrotexture was measured by the sandblot test (ASTM-E-965-96) and the microtexture was analyzed by the British Pendulum Test (ASTM-E-303-93). The economic feasibility of using the alternative materials studied in this article was verified through the analysis of a cost composition of the DNIT (National Department of Transport Infrastructure).

a) base compaction b) base primer c) application of MS d) test run

e) sinking with 500 cycles f) measurement of sinkings g) british pendulum test on plate h) sandblot test on plate

FIGURE 1 Stages of the molding, simulation and measurement of the properties of the MS in the simulator LCPC

3. RESULTS PRESENTATION

3.1 Characterization of Materials

In order to select the granulometry, it was decided to use the materials included in section II of the DNIT (Figure 2), which is the most adopted by the Brazilian road agencies. The results are shown in Table 1 and met the requirements of current specifications.

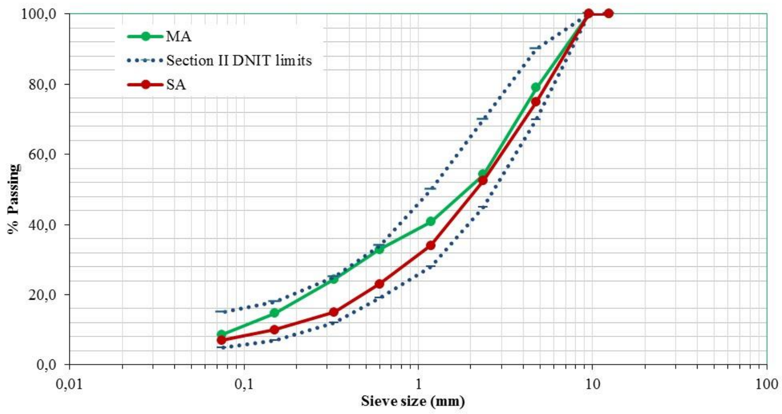

FIGURE 2 Grain Size Curve of Selected Aggregates.

TABLE 1 Summary Table of the Characterization of Aggregates

Tests	MA	AS
Shape Index	0,64	0,96
Los Angeles Abrasion (%)	40,8	17,0
Methylene Blue (mg/g)	1,5	2,0
Sand Equivalent (%)	66,2	83,0
Expansion (%)	Not applicable	0,02
Leaching and Solubilization	Not applicable	Class II (non-hazardous inert)

TABLE 2 Results of Characterization of Asphalt Emulsion CCS-1P

Tests	1ª	2ª	3ª	Specification
Saybolt-Furol Viscosity, s, at 50ºC	35	41	39	70 max.
Screening, 0,84mm, max (%)	0,01	0,01	0,01	0,1
Particle Charge	Positive	Positive	Positive	Positive
Residue by Evaporation (%)	63,6	62,4	63,2	62,0
Penetration at 25ºC, 100g, 5s	58	61	60	45-150
Elastic Recovery, 20cm, 25ºC (%)	73,0	71,0	71,7	< 70
Softening Point, ºC	70	72	67	< 55
Sedimentation (%)	0,8	0,7	0,8	< 5

3.2 Dosing and Analysis of Laboratory Behavior of MS

After the adhesion tests were carried out, it was found that, for SA and MA, it was satisfactory. It was also verified that, for the two types of aggregates studied, it was not necessary the use of additive controlling the rupture time, indicating good compatibility. For the two aggregates, the project found content was 10.8% compared to the weight of aggregate. It is worth mentioning that although the percentage of binder was identical, the consumption of the same when employed AS is higher as a function of its higher specific weight.

The results obtained for surface wear for the two aggregates studied met the limits established in the current specifications, and the SA presented a lower wear when compared to the MA. Regarding the time to release to traffic, the values of the torques obtained for the time of 60min are above the specifications of the standard. Regarding the time to release to traffic, the values of the torques obtained for the time of 60min are above the specifications of the standard.This way, the traffic can be released within one hour, without causing any damage to the quality of the coating just applied. Table 3 summarizes the results obtained in the dosing and analysis of the laboratory behavior performed for the two groups studied.

TABLE 3 Summary Table for MS Dosage

Results	MA	SA	Specification
Adhesiveness	Satisfactory	Satisfactory	Satisfactory
Additive Content (%)	0,0	0,0	-
Binder Content (%)	10,8	10,8	> 10,5
Medium Wear (g/m^2)	252,2	195,3	< 538
Release to Traffic (h)	1,0	1,0	1,0

3.3 Analysis of the MS Submitted to the Laboratory Traffic Simulator

Before starting the test with the simulator, the application rate in kg / m² of MS was calculated. For the case of MS-MA, considering a thickness of 1.5cm, the application rate was 29.83kg/m². For the SA, this rate was higher and equal to 38.33 kg / m². Following the same procedure adopted by Vasconcelos [33], the MS plates were submitted to the simulator test. Figure 3 shows the evolution of the deformation suffered by the MS with MA and SA.

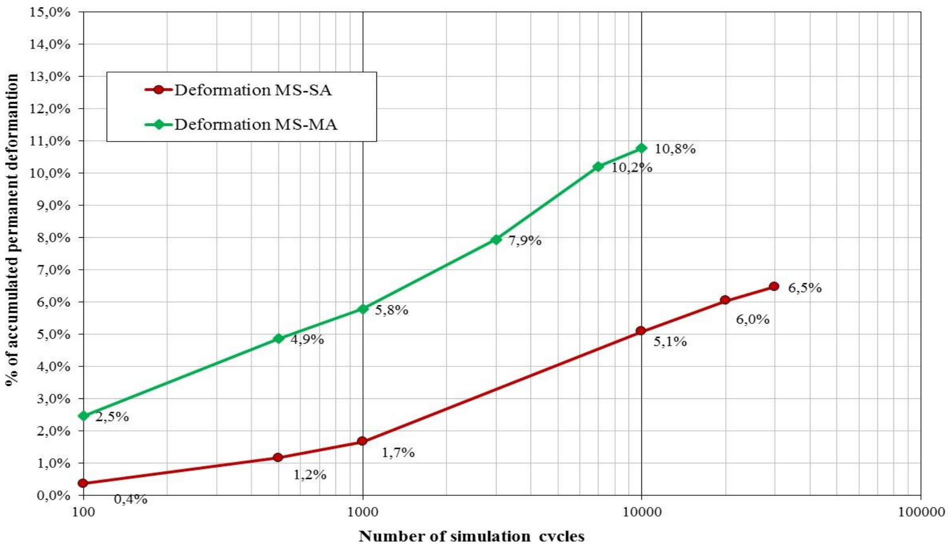

FIGURE 3 Accumulated Permanent Deformation for Both Aggregate

By analyzing the deformation suffered by the plates, it can be seen that the sinking when the AS is used as an aggregate is about 50% lower for 10000 cycles (initial test stopping criterion) when compared to MA. In this situation, it was decided to continue with the test up to 30000 cycles only with the SA, in order to analyze its behavior when submitted to a larger traffic volume, certifying its better behavior with respect to permanent deformation. Based on this, it can be seen that with the SA, the MS resisted better the actions of the simulator. In relation to surface wear and aggregate detachment, none of these phenomena were observed during the simulation, indicating a suitable involvement of the aggregates by the binder and a good behavior of the coating when the two types of aggregate were used.

Regarding macro and microtexture parameters, the results met the current specifications for the studied aggregates. Table 4 shows the summary of the results obtained for the granulometric combinations submitted to the simulation cycles. After conducting the tests in the simulator, it was found that the SA in the MS presented better behavior when compared to the MA.

TABLE 4 Summary of Laboratory Traffic Simulator Trials

Results	MS–MA	MS–SA	Specification
Taxa de aplicação (kg/m²)	29,83	38,83	-
HS (mm) antes	0,78	0,90	< 0,60
HS (mm) depois	0,61	0,70	< 0,60
VRD antes	76	81	< 45
VRD depois	53	59	< 45

3.4 Economic evaluation

Table 5 presents the comparison of the costs of applying the MS with the different aggregates tested. As a form of simplification, Medium Transport Distances (MTD) costs for aggregates and binders were disregarded.

TABLE 5 Comparison of MS Application Costs

FEES/COSTS	MS–MA	MS– SA
Aggregate rate (kg/m²)	26,90	35,04
Binder content in relation to the weight of the aggregate (%)	10,8	10,8
Binder amount (kg/m²)	2,90	3,78
Binding cost (without transport) (US$/m²)	1,80	2,34
Material cost + labor (without transport)	0,63	0,42
Final cost (US$/m²)	2,43	2,76

Analyzing the final application costs in US $ / m², the application of MS with SA was less viable, about 13% more expensive than the MA solution. However, it was observed that its behavior in wear and in the small simulator was better, obtaining a superior durability. This tendency is also observed in other studies that use SA. It should be emphasized that this higher durability should be tested in real-scale experimental sections, so that other factors that may alter coating performance can also be analyzed.

4. CONCLUSIONS

The results obtained in this work showed that the alternative steel metallurgy studied has the potential to be used in MS. The SA was considered viable in the technical and environmental scope.

Regarding the costs involved in the use of the SA, there was an increase of 13% when compared to the mineral aggregate studied in this article. It should be noted that this MA was considered to be of excellent and superior behavior in the region of the state of Ceará/Brazil, and that there are some lower behavioral aggregates that require the use of additives, which increases the costs of MS with MA.

It should also be noted that the laboratory analyzes showed that the MS with SA has better wear resistance and presented the smallest deformations in the laboratory traffic simulator. In addition, road safety standards have all been met. This improved behavior of MS with SA can extend the useful life of the pavement, making the cost-benefit ratio of this alternative a long term advantage.

5. REFERENCES

[1] Associação Brasileira das Empresas Distribuidoras de Asfaltos (ABEDA). Manual Básico de Emulsões Asfálticas. 2ª ed. Rio de Janeiro, RJ, 2010.

[2] Loiola, P. R. R. Estudos de Agregados e Ligantes Alternativos para Emprego em Tratamentos Superficiais de Rodovias. Dissertação de Mestrado, Universidade Federal do Ceará (UFC). Fortaleza, 2009.

[3] Santo, N. R. E.; Reis, R. M. M. Microrrevestimento Asfáltico a Frio. Uma Inovação Tecnológica para Tratamentos de Superfície. Rio de Janeiro, RJ. 1999.

[4] Vale, A. F. Estudo e Aplicação de Microrrevestimento Asfáltico a Frio (MRAF). Dissertação de Mestrado. Escola Politécnica da Universidade de São Paulo, POLI-USP. São Paulo, 2003.

[5] Vale, A. F.; Suzuki, C. Y. Desempenho do Microrrevestimento Asfáltico. 35ª ABPv, Reunião Anual de Pavimentação. Rio de Janeiro, 2004. 1 CD-ROM

[6] Reis, M. Um Estudo da Influência da Granulometria dos Agregados No Desempenho do Microrrevestimento Asfáltico a Frio quanto ao Deslocamento Lateral e Vertical**.** Dissertação de Mestrado. UNICAMP. Campinas, 2005.

[7] Castro, P. B. Avaliação De Agregados Da Região Metropolitana De Fortaleza Para Aplicação Em Microrrevestimento Asfáltico A Frio. Projeto de Graduação. Universidade Federal do Ceará (UFC). Fortaleza, 2011.

[8] Ceratti, J. A. P.; Reis, R. M. M. Manual De Microrrevestimento Asfáltico A Frio – MRAF. Instituto Pavimentar. Rio de Janeiro, 2011.

[9] Federal Highway Adminstration (FHWA). Surface Rehabilitation Techniques: State of the Practice Desing, Construction and Performance of Micro-Surfacing. Washington. Estados Unidos, 1994

[10] Hick, R. G.; Moulthrop, J.S.; Daleiden, J. Selecting a Preventive Maintenance Treatment for Flexible Pavements. Transportation Research Board, National Research Council, Washington, Estados Unidos, 1999. P. 1–12.

[11] Austroads. Sprayed Sealing Guide**.** Austroads. Sydney, Australia, 2003a. C. Guidelines and Specification for Bituminous SlurrySurfacing. Austroads Publication No. AP–T26/03, Sydney, Australia, 2003.

[12] Hein, D.; Olidis, C.; Darter, M.; Quintus, H. V. Impact of Recent Tecnology Advancements on Pavement Life. Annual Conference of the Transportation Association of Canada. St. John´s, Newfoundland and Labrador. Canadá, 2003. 24p

[13] California Department of Transportation (CALTRANS)**.** Maintenance Technical Advisory Guide Volume 1: Flexible Pavement Preservation**.** 2ª ed. California Department of Transportation. California, Estados Unidos, 2009.

[14] Broughton, B; Lee, S. J.; Kim, Y. J. 30 Years of Microsurfacing: A Review. ISRN Civil Engineering. Volume 2012. 2012. 7p.

[15] Ulhman, B. Eco-Efficiency of Microsurfacing – proceedings**.** AEMA-ARRA-ISSA Annual Meeting. Miami. Estados Unidos, 2010. 56p

[16] National Cooperative Highway Research Program (NCHRP). Microsurfacing, A Synthesis os Highway Practice**.** Transportation Research Board. Washington. Estados Unidos, 2010.

[17] International Slurry Surfacing Association (ISSA A-143). Recommended Performance Guideline for Micro Surfacing. Annapolis, MD. Estados Unidos, 2010.

[18] Apparoa, G.; Kumar, R; Amar, D.D.; Ryntathiang, T.L. Green Road Approach for the Sustainable Development in India**.** European Journal of Sustainable Development. Londres. pp. 165-176. 2013.

[19] Ji, Y.; Nantung, T.; Tompkins, B.; Harris, D. Evaluation for microsurfacing as pavement preservation treatment. Journal of Materials in Civil Engineering, 25, pp.540–547. 2013.

[20] Bae, A.; Stoffels, S. M. Economic effects of microsurfacing on thermally cracked pavements. Journal of Civil Engineering, 12(3), pp. 177–185. 2007.

[21] Silva, E.A.; Mendonça, R. L. Brésil: Laitier d'aciérie à tous lês étages. Laitiers Sidérurgiques. Marselha. nº 81, p.11-24, 2001.

[22] Rohde, L. Escória de aciaria elétrica em camadas granulares do pavimento – estudo laboratorial. Dissertação de Mestrado. Universidade Federal do Rio Grande do Sul (UFRGS). Porto Alegre, 2002.

[23] Parente, E. B.; Boavista, A. H.; Soares, J. B. Estudo do comportamento mecânico de misturas de solo e escória de aciaria para aplicação na construção rodoviário na região metropolitana de Fortaleza. XVII Congresso de Pesquisa e Ensino em Transportes (ANPET), 2003.

[24] Santos Neto, P. F. Estudo do Uso da Escória de Aciaria em Camadas de Pavimentos na Região Metropolitana de Fortaleza. Projeto de Graduação. Universidade Federal do Ceará (UFC). Fortaleza, 2007.

[25] Cavalcante, F. C. I. T.; Pereira, S. L. O.; Barroso, S. H. A. Aproveitamento de resíduos provenientes da indústria siderúrgica para construção de pavimentos econômicos do estado do ceará. Livro comemorativo 2010: compilação dos melhores projetos. Odebrecht Construtora. Rio de Janeiro, 2011.

[26] Departamento Nacional de Infraestrutura de Transportes (DNIT). Aplicação de escória de aciaria produzida na ArcelorMittal-Tubarão com redução de expansão, com ou sem adição de argila em base e sub-base rodoviária. Relatório Final, Volume 1. Rio de Janeiro, RJ. 2008.

[27] Castelo Branco, V. T. F. Caracterização de Misturas Asfálticas com o Uso de Escória de Aciaria como Agregado. Dissertação de Mestrado. Universidade Federal do Rio de Janeito (UFRJ). Rio de Janeiro, 2004.

[28] Pedrosa, R. A. A. Estudo de viabilidade técnica e econômica do uso de agregados de escória de aciaria em concreto betuminoso usinado a quente. Dissertação de Mestrado. Universidade Federal de Ouro Preto (UFOP). Ouro Preto, 2010.

[29] Silva, R. G. O. Estudo laboratorial do desempenho mecânico de misturas asfálticas com resíduos industriais de minério de ferro. Dissertação de Mestrado, Universidade Federal de Ouro Preto (UFOP). Ouro Preto, 2010.

[30] Tavares, D. S.; Motta, L. M. G.; Oda, S.; Ramos, F. R. Avaliação Laboratorial de Mistura Asfáltica do Tipo SMA com Agregado Siderúrgico. Dissertação de Mestrado. Universidade Federal do Rio de Janeiro. Rio de Janeiro, 2012.

[31] Pereira, S.L.O. Avaliação dos Tratamentos Superficiais Simples, Duplo e Triplo de Rodovias através do Emprego de Diferentes Agregados da Região Metropolitana de Fortaleza. Dissertação de Mestrado. Universidade Federal do Ceará (UFC). Fortaleza, 2013

[32] Rocha, F. L. L. Utilização do Agregado Siderúrgico (escória de aciaria) em Revestimento Asfáltico Tipo Tratamento Superficial. Dissertação de Mestrado. Universidade Federal de Ouro Preto (UFOP). Ouro Preto, MG, 2011.

[33] Vasconcelos, M. A. G. Estudo sobre Emprego do Cape Seal em Revestimentos Rodoviários do Estado do Ceará. Dissertação de Mestrado. Universidade Federal do Ceará (UFC). Fortaleza, 2013.