The Influence of Unusual Materials as Prospective Fillers in the Hot Mix Asphalt

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Abstract. Among the factors that influence directly the durability of the asphaltic layer on pavements, the type and percentage of filler in the hot mix asphalt pavement (HMA) is a great player. The most traditional fillers, the Portland cement and the hydrated lime, are well known for resisting to weather variations and adding extra features to the hot mixtures. The glass powder, the cladding waste (gotten from clay bricks), the ashes of rice husks and laterite powder are proposed as substitutes to the traditional ones. The materials have been sieved and classified by fitting the powder on the filler grain size required by Brazilian Rules, eventually they have been tested with asphalt 50/70. The glass powder performed a Thermic Susceptibility Index (IST) of -0.69 for 5% in weight of filler and -0.75 for 10% in weight of filler, proving that this material satisfies the Brazilian specification DNIT-EM 095/2006; on the other hand, the laterite powder presented an IST of -0.61 for 5% and 0.32 for 10%. After executing the Softening Point, Penetration and Flash Point tests, it has been confirmed that the glass and laterite powder are recommended materials as potential substitutes to the Portland cement, however the first one performs better under balmy temperatures due to its negative IST; the cladding powder and the rice husks turns the mixtures too rigid and breakable on percentages close to 10%.

1. Introduction
The constitutive elements of the hot mix asphalt play an important role in the entire group, the functions of each part are relevant; the aggregates transfer the load on the pavement surface to the ground through frictional strength, the asphalt acts as the binder, putting the aggregates together in a working position; the filler fills the voids among the aggregates, changing some important features of the Hot Mix Asphalt (HMA). Besides, the filler contributes hardening the mixture, being able to help or harm the appearing of cracks along the path, by that, this paper develops several tests (Softening Point, Penetration and Flash Point) with four pulverized materials (rice husk ashes, cladding waste, glass and laterite) comparing the results with the traditional filler Portland Cement and propose some of them as substitutes of the Cement.

In Brazil, the standards for pavement design are set through two main agencies, the first is the Brazilian Association for Technical Norms (ABNT) which sets the range values of the most important parameters, however, the National Department for Terrestrial Infrastructure (DNIT) is the most important organism that executes and monitors Brazilian Interstate Highways, and, for instance, it has its own standards which have been used for the performed tests.
According to DNIT-EM 367/97 [1], filler is an inert material in comparison to the others in the HMA, passing at least 65% through the sieve #200 (0.075mm), as it is shown in Table 1, it fills the voids, being an active part of the mastic (binder, filler and air), besides, affects the characteristics of compaction and the optimum percentage of asphalt in the mixture. Overall, the filling material (filler) enhances the rheological, mechanical, thermic and water susceptibility behaviour, this is the reason why some authors do not classify it as an inert material as it is classified in Brazilian standards.

### Table 1. Filler granulometry adapted from DNIT ME 367/1997 [1]

| Sieve   | % passing minimum |
|---------|-------------------|
| # 40    | 100               |
| # 80    | 95                |
| # 200 (0.075mm) | 65                |

Another point of discussion is the determination of the percentage of filler in the hot mix asphalt, Moizinho (2007) [2] observed that mixtures containing more than 6% of filler over the total weight tend to constitute mixtures too expensive, since it starts requiring a greater percentage of binder as well, besides that, the hardening of the mixture may get excessive, and fill most of the voids that could avoid the exudation of the pavement.

DNIT classifies the Brazilian asphalt through the penetration point and for this paper, the used asphalt is set in a range from 5 to 7 mm of penetration in a 25-degree-Celsius room during 5 seconds of testing, the binder is named Petroleum Asphalt Cement (PAC 50/70, CAP in Portuguese) and it is classified according the Table 2.

### Table 2. Threshold points for Petroleum Asphalt Cement (PAC) 50/70 after Chyba! Nenašiel sa žiaden zdroj odkazov.

| Characteristic                          | Range   | Standard Norm                        |
|----------------------------------------|---------|--------------------------------------|
| Penetration Point (100g, 5s, 25°C)     | 0.1mm   | NBR 6576, D 5, 155/2010              |
| Softening Point, minimum ºC             | 46      | NBR 6560, D 36, 131/2010             |
| Maximum increase of Softening Point     | 8       | NBR 6560, D 36                       |
| Minimum ductility at 25°C               | 20      | NBR 6293, D 113, 163/1998            |
| Saybolt Furol Viscosity                 |         |                                      |
| At 135ºC, minimum                       | 141     | NBR 14950, E 102, ME 004/94          |
| At 150ºC, minimum                       | 50      |                                      |
| At 177ºC, minimum                       | 30-150  |                                      |
| Thermic Susceptibility Index (IST)      | (-1,5) to (+0,7) |                  |
| Flash Point, minimum                    | 235     | NBR 11341, D 92, ME 149/94           |

*To be tested in long term conditions.
*For initial ductility, minimum value is 100cm.

2. The Prospective Materials and Tests

Different types of filling materials were used, the tests were performed with the binder and the filler only, not taking the full mixture (the aggregates were not considered), the percentages were 0% of filler, 5% of filler and 10% of filler in the weight of the mixture PAC(Asphalt)/Filler.

The ashes of the rice husk were obtained from the burning of the rice husk in an electric muffle kiln at 650ºC for two hours; the laterite, glass piece and cladding waste were pulverized in a mill for 45, 30 and 30 minutes respectively. Eventually, the pulverized material was sieved and set into the classification as it is shown in the Table 1, the obtained materials are shown in Figure 1.
The four fine materials and Portland Cement were tested with the percentages described in the first paragraph for the softening, penetration and flash point in order to establish the Susceptibility Thermic Index (STI) and understand the influence of the adding of the fine materials.

![Image](image.png)

Figure 1. A. Rice Husk Ashes, B. Laterite Powder, C. Cladding Waste Powder; D. Glass Powder and E. Portland Cement.

2.1. The Softening Point
The softening point is an empirical measure that correlates the softening temperature of the asphalt under a standard flow condition. In Brazil, the test is standardized by DNIT-ME 131/2010 [4] which describes the ring-and-ball apparatus and the steps to get the thorough softening temperature. Briefly, the test consists on a small steel ball with standardized weight and dimensions set in the center of an asphalt sample inside a steel ring; the ring-and-ball group is put inside a Becker full of water and the temperature is incremented by 5ºC, the softening point, is the temperature needed for the sample to reach the bottom of the Becker.

2.2. Flash Point
The flash point is a test used for the handling safety of the bituminous materials during the transport, storage and setting on the pavement surface. It represents the minimum temperature able to burn and set the initial flames of the bituminous material. The values for flash point are generally found to be higher than 230ºC, this test is used for checking the existence of solving substances which might decrease the flash point, thus, decreasing the safety of the hot handling of the material. According to the specification [5], the temperature is incremented fast at the beginning of the test (about 17ºC per minute) and slows down, as it reaches the flash point (increments of 5ºC at the very last minutes), test finishes after 5 seconds of the flame’s beginning.

2.3. Penetration test
The penetration test measures the distance in tenths of millimeter that a standard needle penetrates vertically in the bituminous sample under a known load, time and temperature. When there is no specific indication, the test is executed under 25 ± 0.1ºC with 100 ± 0.5g during 5 seconds, so, the asphalt will be classified as: hard (penetration between 30 and 45 x 10^-1 mm), medium (penetration between 50-70 and 85-100 x 10^-1 mm) or soft (penetration between 150 and 200 x 10^-1 mm). The norm DNIT-ME 155/2010 [6] is the Brazilian standard and describes the procedure and apparatus used in the test.

2.4. The critical concentration
As the concentration (C) of the system binder-filler increases, the closer the particles get to the aggregates in the hot mix, and the smaller will be the volume of the voids, hardening the mixture, eventually. When the concentration (C) reaches a critical concentration (Cs), the rigidity of the mixture
starts to harm the resistance to fatigue of the pavement [8]. Then C must be set under Cs and Santana (1995) [8] recommends it to be 10 to 20% smaller than Cs, being the concentration defined by the Equation 1.

\[ C = \frac{1}{\frac{\% b f}{\% f} + 1} \]  

(1)

Where:
C: is the concentration;
\% b: percentage of asphalt, in weight, in the overall sample;
\% f: percentage of filler, in weight, in the overall sample;
\( \gamma_f \): unit weight of the filler;
\( \gamma_b \): unit weight of the asphalt (bitumen).

The ideal concentration is the one that works adequately under the characteristics of the regional climate, permitting the filling of the necessary voids, but not all of them, in a way to avoid the exudation as the temperature increases. According to Bianchetto (2007) [9], the critical concentration (analytical term introduced in Argentina) is the concentration that makes the mastic too rigid, resulting in a fragile system binder-filler, reducing the flexibility, cohesion and durability. This critical concentration comes from the rearrangement of the filler particles deposited in the bituminous material. The critical concentration is given in function of the deposited filler material in kerosene (material with characteristics close enough to the bituminous material), the Cs is given by Equation 2.

\[ C_s = \frac{W}{V \times \gamma_f} \]  

(2)

Where:
W: weight of the dry filler;
V: volume of the deposited filler in anhydrous kerosene after 24 hours;
\( \gamma_f \): unit weight of the filler.

2.5. Thermic Susceptibility Index (IST)

The Thermic Susceptibility of the binder is assessed with a big row of tests under different temperatures, and, the lower the variation in the rigidity, the lesser is the thermic susceptibility of that given binder. Bituminous materials that are highly susceptible to thermic variations are not desirable, since there is a tiny workable range of temperature. Thus, that asphalt under small changes in the temperatures becomes either too soft or too hard, changing its consistency easily. The trend to cracking is going to be an issue under low temperatures and, in the other hand, issues for compaction are going to be a challenge during warm seasons.

Usually, the IST or Penetration Index is measured by the procedure proposed by Pfeiffer and Van Doormaal. This index depends on the softening point and on the penetration point at 25ºC. The Equation 3 presents the formula, the maximum value for the IST is close to 20 and it happens when the penetration points is close to 800 x 10^{-1} mm.

\[ IST = \frac{500 \times \log_{10} P + 20 \times SP - 1951}{120 - 50 \times \log_{10} P + SP} \]  

(3)

where:
IP: Penetration Index or IST;
P(x10^{-1} mm): penetration point at 25ºC for 5 seconds;
SP(ºC): softening point of the bituminous material.
Workable values for IST range from -1 to 1, and, according to each country the values are set according to its climate features. Brazil defines the range show in Table 2.

3. Results and discussions

The results shown in this section were performed in laboratories certified by the Federal University of Roraima and by the Brazilian Corps Engineers of the Army, every test was performed more than once and normalized, disregarding values out of the standard deviation, and the averages are shown according to the standards set by ABNT and DNIT.

The concentration of the system binder-filler is shown for different percentages of filler weight in Table 3, the critical situation was evaluated as well according to the Equation 2, the unit weight of the fillers were obtained with the use of a pycnometer.

**Table 3. Concentrations of filler for different weight proportions.**

| Material                  | γ (kg/m³) | 5%  | 10%  | 15%  | 20%  | 25%  | 30%  | CS   |
|---------------------------|-----------|-----|------|------|------|------|------|------|
| PAC – Asphalt             | 882       | 0.465 | 0.635 | (0.723) | (0.776) | (0.813) | (0.839) | 0.712 |
| Cement                    | 1016      | 0.423 | 0.594 | 0.687 | 0.745 | 0.785 | 0.815 | 0.948 |
| Glass Powder              | 1205      | 0.423 | 0.594 | 0.687 | 0.745 | 0.785 | 0.815 | 0.948 |
| Rice Husk                 | 259       | 0.773 | 0.872 | 0.911 | 0.932 | 0.945 | 0.953 | 1.066 |
| Cladding Waste            | 821       | 0.518 | 0.682 | 0.763 | 0.811 | (0.843) | (0.866) | 0.826 |
| Laterite Powder           | 1684      | 0.344 | 0.512 | 0.611 | 0.677 | 0.724 | (0.759) | 0.757 |

*Values between parenthesis ( ) are over the critical concentration.

From the analysis of Table 3, every potential material reaches the critical concentration after the 25% in weight only, in exception of the Portland Cement, the traditional filler, that reaches the critical value at 15% in weight; the rice husk and glass powder did not reach the Cs before the 30% and for the rice husk, the Cs reaches the unit due to the light weight of the rice husk ashes. After, checking the results, the proportions used in the tests were 0, 5 and 10% as described before due to the inexistence of critical situation in any of the five fillers performed.

**Table 4. Results obtained for the tests.**

| Proportion | Softening Point (ºC) | Flash Point (ºC) | Penetration (x 10⁻¹ mm) | IST |
|------------|----------------------|------------------|-------------------------|-----|
| PAC 50/70  | -                    | 50.50            | 275                     | 67  | -0.35 |
| Cement     | 5.00%                | 51.25            | 286                     | 73  | 0.07  |
|            | 10.00%               | 52.40            | 287                     | 65  | 0.04  |
| Glass Powder| 5.00%             | 48.50            | 280                     | 72  | -0.69 |
|            | 10.00%               | 49.75            | 288                     | 62  | -0.75 |
| Cladding Waste| 5.00%             | 52.85            | 284                     | 71  | 0.39  |
|            | 10.00%               | 49.50            | 286                     | 73  | -0.38 |
| Rice Husk  | 5.00%                | 52.55            | 285                     | 70  | 0.28  |
|            | 10.00%               | 57.50            | 288                     | 55  | 0.76  |
| Laterite Powder| 5.00%            | 51.65            | 280                     | 54  | -0.61 |
|            | 10.00%               | 52.25            | 279                     | 73  | 0.32  |

The softening point for the Petroleum Asphalt Cement (PAC), the binder, with no adding of fine material is 50.5ºC, compatible with the expected value in Table 2. The cladding waste and glass powder, even though presenting a percentage smaller than the critical situation decreased the softening point,
even for higher percentages (25%), showing that they are not adequate in locations with higher temperatures.

Briefly, the fillers which increased the softening point of the binder were the ashes of the rice husk and the laterite powder. The ashes joined to the asphalt (PAC) in the proportion of 10% in weight increased the softening point in 11.5ºC, over the minimum of 46ºC according to DNIT, in the other hand, it exceeded the maximum increase of 8ºC demanded by the test used to assess the aging of the Hot Mix, RTFOT.

![Figure 2. Results obtained for the softening point (ºC).](image)

The results for the Flash Point shown in Figure 3 demonstrate that the adding of filler increase the temperature of ignition, but it stays steady around the 280ºC, and that, the unit weight of the fillers, do not change, that much, the behaviour of the flash point trendline as the proportion increases. Since, it is a safety test and that all materials increased the flash point from 275ºC to higher temperatures, every filler tested has shown positive results.

![Figure 3. Results obtained for the flash point (ºC).](image)

The results for the penetration test shown in Figure 4 demonstrate a tendency to increase the rigidity of the sample as the filler proportion is increased. Considering, this test only, the glass powder could be an interesting substitute for the cement, since its behaviour was quite similar. The other materials presented a steady evolution of the penetration, meanwhile, the ashes of the rice husk started a strong decrease in the penetration.
A third proportion (50% in weight) was executed to assess the evolution of the increase of rice husk, however, as the ashes are too light, it demanded a great portion of this material to compose the 50% of the weight of the system binder-filler, so the penetration test with this proportion was not executed, since it pulverized the entire system, not becoming a flowing group as it is shown in Figure 5.

The last and most important parameter is the Thermic Susceptibility Index (IST) that made possible to correlate the penetration and softening point in a way to assess the feasibility of the system binder-filler on the pavement, according to DNIT-EM 095/2005 Chyba! Nenašiel sa žiaden zdroj odkazov., as it is shown in Table 2, the IST needs to range from -1.5 to +0.7, however, the ashes of the rice husk, when used in 10% of weight, was the only fine material not adequate, since it presented a value higher than +1.5 performing a crack-able binder-filler system.

The results smaller than zero for IST are more adequate for cold/dry regions, while the positive values are more adequate for warm/humid conditions, values close to zero, as the ones obtained for the adding of the cement, show a good behaviour of the system in any weather conditions, meanwhile the glass powder tends toward a negative IST, softening the mixture; the ashes trend to positive ISTs, hardening the mixture; and the other materials keep in an average behaviour.

Figure 6 shows the results for the IST by solving the Equation 3, the results are inserted in the orange lines, which represent the adequate range for Brazilian standards.
4. Conclusions

The Portland Cement (CP II) is the most used filler in Brazil. It is added with ground granulated blast furnace and, generally, it is the 32 MPa 28-day strength cement and it was validated as a good filler in this paper, despite its low increase in penetration.

The glass powder reduced the softening point and the penetration, resulting in a negative thermic susceptibility index, what demonstrates a good behaviour for cold regions, since the pavement becomes more flexible with its adding. The cladding waste powder hardened the mixture, the softening point increased and the penetration decreased in comparison to the system without adding of filling material, this demonstrates a system less flexible and more adequate to warm regions.

The ashes of rice husk harden the system binder-filler with reduced proportions what showed a good performance for warm regions, where a less flexible pavement is desirable, the reduced unit weight is an issue that matters since the proportion needs to be quite low to keep the mix adequate, this is a good response, since small amounts of these ashes are enough to harden the mix in an adequate way. The laterite powder performed well and presented good results for wide-range temperatures, since it may have a positive and a negative IST, the use of this filler is cheaper and more adequate for Brazil, since this mineralogy is quite common in the country.

Concerning the critical concentration (Cs), all the mixtures of binder-filler were performed with 5 and 10% proportion in weight, a value smaller than the critical ones shown in Table 3, the point is that every performed material in this paper are adequate to be used in the pavement design, regarding the specific issue of the regional weather that is going to control which of the prospective material is more adequate, cheaper and more abundant in the region of construction.

At last, many of the problems in the pavement studies are related to the appearing and propagation of fatigue cracks. The permanent and thermic deformations are some of the issues related to the change in temperature and characteristic of the filling material. So, a flexible pavement with a longer-term use is desirable, then the interaction between the binder and the fillers is going to be one of the most influent players.

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