ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 11, Issue, 02, pp. 44850-44855, February, 2021
https://doi.org/10.37118/ijdr.21245.02.2021

RESEARCH ARTICLE OPEN ACCESS

SUSTAINABLE PRACTICES IN ASPHALT PAVEMENTS AND THEIR POSSIBLE APPLICATIONS IN THE BRAZILIAN MARKET

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ARTICLE INFO

Article History:
Received 11th December, 2020
Received in revised form
22nd December, 2020
Accepted 15th January, 2021
Published online 28th February, 2021

Key Words:
Pavement Maintenance;
Recycled Materials;
Warm Asphalt Mixes.

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ABSTRACT

The construction and maintenance of pavements consumes a large quantity of resources. The scarcity of these resources and, increase in prices, suggests that new techniques need be employed. The transition to a circular economy has been a solution for economic and environmental issues, to make resources available in the future. In road engineering, many studies point to the need for a better standard of sustainability, with technical and economic feasibility. The objective of this work is to present the techniques available that represents some of the most widely used sustainable practices in the world, applied technology, its advantages, and disadvantages and, its market share, that extend the life cycle of pavements, reducing the consumption of aggregates and binders using recycled materials, reducing the production temperature, which implies less consumption of fossil fuels and emission, less work and travel time, promoting on-site techniques and avoiding the final disposal of waste in landfills. Three sustainable practices were analysed: maintenance, use of recycled materials and technologies of warm asphalt mixes. This work concludes that there is a lack in current solid waste policy in the country and the current paving standards that need be reviewed focusing on sustainability, especially regarding recycling processes.

Citation: ***Avila M. Giovani, Oda Sandra, Guerrero Francisco and Carrasco F. Pedro. 2021.*** "Sustainable Practices in Asphalt Pavements and their Possible Applications in the Brazilian Market*", international journal of development research*, 11, (02), 44850-44855.

INTRODUCTION

In a country where the main mode of cargo and passenger transportation is by road, the excess load, and the high number of requests cause damage to the infrastructure of the pavements that must be constantly repaired. Approximately 50% of Brazilian roads have regular or poor conditions, which leads to higher operating costs (Figure 1). This cost translates not only into an economic issue, but also into environmental issues due to the increased fuel consumption of the vehicles. In 2010, the National Solid Waste Policy (PNRS) was instituted, which is Law No. 12,305 / 10 with the objective of promoting sustainability practices and increasing the country's competitiveness. The law focused on recycling and reusing materials, especially inert materials, in which the materials obtained from the pavement are inserted. An inert material must be stored separately to be reused in the future. However, even after the law, the use of recycled asphalt pavement (RAP) and recycled aggregate (RCA) is reduced compared to other countries. With a low-density road network, Brazil occupies the 10th place in the global production of asphalt, presenting an increase of more than 100% since 1995 (Figure 2). Considering that 95% of Brazilian paved roads are made of asphalt lining, most of the asphalt production is destined to maintenance operations (Benucci, *et al*., 2010).

From the information raised above, some conclusions can be drawn:

- Investing in the quality of road infrastructure and management is essential to increase Brazil's competitiveness, ensuring the safety of people and cargo, promoting sustainability at the national level (CNT, 2016).
- The current paving policy is not achieving the expected result: About 50% of the kilometres run have problems with paving, while the production of asphalt increases continuously.

In this context, such results indicate the need for a change in the paving policy and in the development of techniques that lead to a return for the benefit of maintenance, sustainable production, and the close relationship between the end of the life cycle and the production of materials. The goal is to create closed or open cycles in which resources do not end up as waste. To achieve this goal, the entire life cycle (material production; pavement design; construction; use; maintenance and preservation; and end of life) must be considered. The thought of a closed-loop system can offer a number of advantages (Van Dam *et al*., 2015): avoiding the generation of waste in the first place; create closed-loop economies with additional employment opportunities in recycling industries; transforming industries with better use of resources, cleaner production processes and, above all, expanding the responsibility of the first producer; promote economic benefits through more efficient use of resources; conserve landfills and reduce the need for new landfills. Three sustainable practices will be presented and analysed in this study: maintenance, use of recycled materials and technologies of warm asphalt mixes (Warm Mix Asphalt - WMA).

Maintenance: Pavement maintenance is inherently a sustainable activity. It often uses low-cost treatments and low environmental impact to prolong or extend the life of the pavement, postponing the need for the main rehabilitation activities. This conserves virgin energy and materials while reducing greenhouse gas (GHG) emissions over the life cycle (Van Dam *et al*., 2015). It is important to consider that during the projected life of any road, the pollution generated by traffic is much greater than during the construction of the pavement. Energy consumption and emissions from traffic over its lifetime exceed energy consumption and emissions from other stages of the life cycle by 2–500 times, depending, for example, on the analysis period, traffic intensity and alternative road construction (Anthonissen *et al*., 2016).

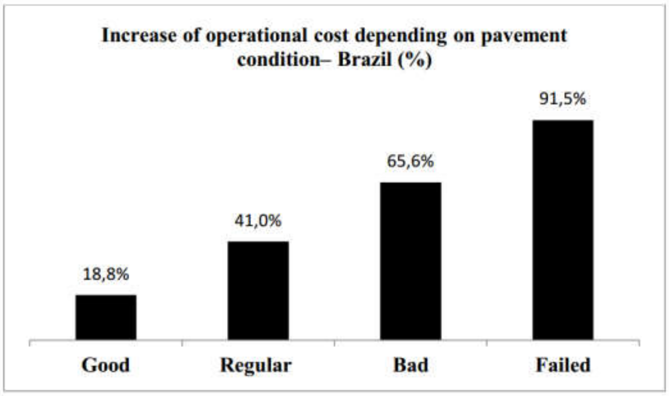

Figure 1. Increase of operational cost depending on pavement condition in Brazil (CNT, 2016)

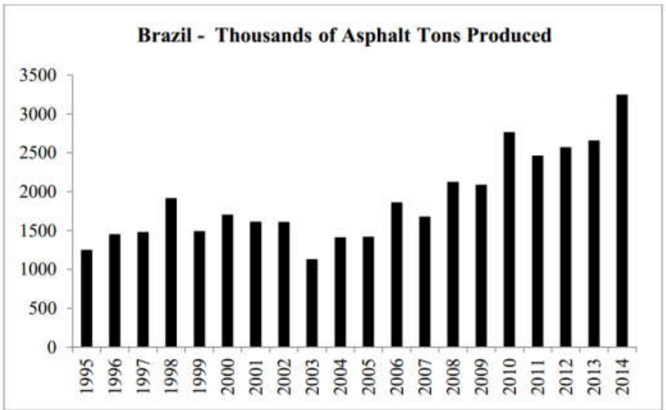

Figure 2. Thousands of Asphalt tons produced per year in Brazil (1995-2014) (United Nations)

Anthonissen *et al*. (2016) evaluated the intermediate maintenance period as a factor of great influence on the environmental impact during the life cycle of the road pavement, finding in the literature a reduction of the environmental impact of at least 10% in each impact category when the intermediate maintenance period of the surface layer (coating) is extended from 10 to 14 years and a reduction of the potential global warming by 25% when the intermediate maintenance periods are extended from 7.5 to 12.5 years for the coating and 15 to 25 years for the base. The environmental impact caused by traffic disruption during maintenance interventions is another important issue. Reducing the duration of the work for a complete reconstruction (base, sub-base, and coating) by 3 days results in significant reductions in emissions and energy consumption by traffic. The number of reduced emissions of carbon oxide (CO) and particles (PM) is almost equal to that caused by the construction of the road itself. This indicates the importance of limiting traffic congestion during road works. For example, in the United States, road construction and maintenance activities are responsible for 10% of congestion, which caused an annual fuel loss of US$ 700 million (Van Dam *et al*., 2015).

Researchers and field professionals say that the lack of preventive maintenance of the pavement is one of the main causes of its early degradation. The lack of preventive maintenance planning is part of the Brazilian culture and would be so incorporated into the practices of road agencies that the budget for carrying out this activity is often not even foreseen in the planning of a new highway (CNT, 2017). It is important to note that in Brazil the pavement design is planned for 10 years, while in other countries this period is longer, for example, 20 years in the United States or in Portugal. A 20-year project requires mandatory consideration of maintenance activities, requiring more stringent specifications to maintain a high-level condition. The lack of maintenance planning generates a high economic impact and reduces pavement performance. When maintenance is applied, the cost is lower, and the duration is longer (CNT, 2017). The lack of a database with information on pavements in Brazil is another important issue. The creation of a national database containing different pavement designs, with data on construction, performance, and life cycle, including information on climate and traffic loads. The idea of a database would be taken from the American program LTPP - Long Term Pavement Performance, started in 1987 with the aim of understanding why some floors perform better than others, to adopt best practices and develop improved floors in the future. This program is estimated to have saved about US$ 2.5 billion (Walker, 2015).

Recycled Materials

The pavements are composed of aggregates and asphalt. Asphalt is mainly used as a binder and in the surface layer (asphalt coating. Recycled materials can be used to replace part of the virgin materials. Between 90 - 95% of the surface layer is aggregated, while the other 5 - 10% is asphalt.

When the pavement reaches the end of its useful life, it can:

- Remain in place and be reused as part of the support structure for a new pavement.
- Be recycled.
- Be removed and disposed of in landfills (Van Dam *et al*., 2015).

Each of these activities has economic and environmental costs that must be considered, for example, consumption of raw materials, expenditure on energy, emissions. Likewise, there are economic and environmental costs for the other stages of the pavement's life cycle, production of materials, construction, and maintenance of the pavement. Therefore, pavement end-of-life activities can impact sustainability factors, such as waste generation and disposal, material recycling, and should be considered in a comprehensive life cycle assessment (Van Dam, *et al*., 2015).

Aggregates: Aggregates make up most of the mass and volume in a pavement structure, whether used pure or in a mixture with other materials. Although households have a relatively low cost and low environmental impact, they can have a significant impact because they are consumed in large quantities. The greatest environmental burden associated with aggregates is transportation. For the base and the sub-base, two main recycled materials can be used as aggregates: recycled asphalt pavement (RAP) and recycled aggregate (RCA). It is important to note that Brazilian legislation (Standard ABNT NBR 1004) does not allow the use of recycled aggregate in the base layer if traffic is considered heavy or medium, being limited to traffic lanes with $N \leq 10^6$ repetitions of the standard 80kN axis during the project period.

RAP comes from milling. Asphalt pavements have reuse rates of 99% in the USA, so RAP is commonly used in both aggregate and asphalt. Unfortunately, Brazil does not yet have any statistics on its use. In general, the performance of RAP applied in layers of granular base or sub-base, has been described as satisfactory, good, very good or excellent (Chesner *et al*., 1998). Some experimental stretches have been made in Brazil with RAP as a granular base material in heavy traffic routes, and the results show that the recycled material presented gains in the studied parameters, mainly in the rigidity, due to the curing process of the materials used, in addition to appropriate behaviour for traffic (Andrade, 2017). According to Van Dam *et al*. (2015), recycled materials should be used as a substitute for virgin aggregate, in new asphalt concrete. On the other hand, the materials discarded in civil construction (civil construction waste), with emphasis on the RCA, have their "greatest use" as an additive (aggregate product). Its utilization percentage is different depending on the country. The Netherlands has a recycling rate of 99% while in Brazil it ranges from 6% to 21% (ABRECON, 2015).

The percentage of use in Brazil has been growing over time. Proving such facts, the number of recycling plants increased considerably, from 319 in 2015, compared to only 48 in 2009 (ABRECON, 2015). The use of these materials can improve the stiffness of a base or sub-base compared to the conventional base or sub-base, thanks to the hydration of the residual cement in the crushed aggregates that provides an increase in the stiffness modules of the base / sub-base layers, which leads to improved pavement performance (Chai *et al*., 2009). An advantage of RCA is the price, in Rio de Janeiro the value of the base cubic meter made of graduated virgin gravel is almost double compared to the price of recycled construction aggregates, R$ 108.15 versus R$ 54.16 (Catalog of items SCO - RIO, 2017). Even with this difference, the use of RCA is still low. The main causes of the difficulty in marketing recycled aggregate according to Brazilian producers are the lack of legislation that encourages consumption (31%), the high tax burden (26%) and market recognition (26%) (ABRECON, 2015). Other options, such as the application of extra landfill fees, as many European countries do, can help producers to look for alternatives in recycled materials (Schimoller *et al*., 2000). In general, the use of RCA has performed well as a base aggregate. For example, in Louisiana, USA, the Department of Transportation, after evaluating different buildings using RCA, concluded that performance is defined by compliance with material specifications and good construction methods (Bennert and Maher, 2008). In Brazil, additional research must be developed in different experimental sections, monitoring its performance to allow the use of RCA as an aggregate for medium and heavy traffic highways.

Binders: The asphalt binder in asphalt concrete is responsible for a significant portion of the total environmental impact of the mixture due to the impact of oil acquisition and refining (Van Dam, *et al*., 2015). Economically, about 40%-50% of the cost of a ton of HMA is asphalt binder (Catalog of items SCO - RIO, 2017). A major obstacle to increasing the use of pavement recycling in Brazil is the belief that the performance of the recycled layers is inferior to the performance of conventional pavements. However, detailed evaluations show that recycled asphalt mixtures, designed and produced with adequate control, perform similarly to virgin mixes (Fonseca *et al*., 2015).

RAP: RAP can be reused with "in situ" techniques, hot or cold recycling, or transported to a recycling plant where it is stored and processed and then introduced into the production of a new mixture. From an environmental point of view, recycling 'in situ' has more benefits than recycling done at the plant, mainly because transport is reduced in 100% because the materials will be recycled on site. However, cold, and hot recycling 'in situ' often requires an additional surface layer of virgin asphalt concrete to perform well. Consequently, from a functional point of view, these techniques show worse results and their technology still needs to be improved. developed. As a result, plant recycling is more widely used worldwide. In United States, 99% of American producers use RAP in their mixtures. As well as it happens with the maintenance of the asphalt pavement, the unavailability of data makes it difficult to spread the use of RAP in the Brazilian market.

Because it is a product with a long history, its use began in the early 1980s, but today the most controversial question is not whether the asphalt pavement with RAP is better or worse, whereas several studies indicate that 15% of RAP does not have influence on the final mixture and on the pavement life cycle (Petho and Denneman, 2016). The relevant question has become the extent to which mixtures are still high performing and economically viable. In general, the percentage of RAP in the new asphalt mixture is limited due to the difficulties of mixing RAP with virgin materials, without an excessive increase in mixing temperatures, which would accelerate the aging process of the binder and increase energy consumption and emissions during manufacture. Thus, in practice, the amount of RAP in a hot recycled mixture is limited to less than 30% in many countries (Dinis Almeida *et al*., 2016). Three main problems related to the use of RAP are: production temperature, moisture content and workability. The use of a high proportion of RAP reduces workability and increases the compaction of the mixture due to the aged rigid binder associated with RAP (Farooq and Mir, 2017). Regarding the production temperature, the RAP cannot be mixed at the same temperature as the virgin material, as the residual binder would be lost and can be added in two ways: cold in the mixer together with the preheated or preheated virgin materials (for example, by parallel drum) before being added to the mixture with asphalt. Overheating of virgin aggregates before introducing RAP into the drum is a common practice to avoid direct heating of RAP materials. The practice may require extra use of fuel and energy, which would eliminate the economic benefits of using RAP (Aurangzeb and Al-Qadi, 2014).

Cold recycling is easiest and only a few additions to the asphalt plant are necessary to enable it, but the main disadvantages are the higher temperature of virgin materials and a longer mixing time at high recycling rates. Some countries limit a maximum of 20% of the bitumen in the asphalt mixture from RAP when applying cold recycling (Anthonissen *et al*., 2016). On the other hand, the implementation of a parallel drum requires extensive adaptations of the asphalt plant with greater investments, but it is a more efficient approach to recycling. In Japan, most factories use a separate drum for drying and heating of RAP - parallel heating method (West and Copeland, 2015). Another major problem is the moisture content. The moisture content of the aggregates directly affects the energy required for the drying process, that is, a 4% increase in the water content implies a 60% increase in the energy for drying the aggregates (Thives and Ghisi, 2017). The fuel for the burners that heat and dry the aggregates is the dominant source of emissions, accounting for 80% of the total CO_2 produced, while electricity accounts for 20%. Most of the thermal energy is used to dry the aggregate. A 2% reduction in the input moisture content would save 8.7kWh and 2.02kg CO_2 per ton of asphalt mixture. The moisture content of the aggregates is a particularly important parameter to control the performance of an asphalt plant. It depends on the extraction procedure in the quarry, how the piles of aggregates are protected from rain and how the operator collects aggregates from the pile before to put them in the silos of the plant.

One way to partially circumvent this increase in energy consumption may be to decrease the temperature of the hot mixture, whenever possible. The energy demand is about 2.62kWh for an increase of 10°C in the temperature of the mixture and 8.21kWh for each 1% increase in the moisture content. Lessons on how to optimize the use of RAP in Brazil should be drawn from Japan. The Asian country has the highest average of RAP in mixtures with 47%, reaching 73% in some areas of the country (West and Copeland, 2015). Many of the practices are related to humidity control before RAP is added to the mix. Some of the standard practices used in Japan are as follows (West and Copeland, 2015):

- Stocks are covered and stored on a paved surface.
- The moisture content and dust of the RAP is minimized during crushing, processing, and storage.

- Residual RAP binders are recovered and tested to assess their rigidity.
- The RAP is fractionated, and the plants are equipped with several RAP feeding compartments.

In Batch plants are widely used in Japan, which allows better control of asphalt mixtures. In Brazil it is possible to find discontinuous and continuously mixed plants in similar proportions. Unlike Japan, aggregate stocks in Brazil are usually located in uncovered areas, close to the asphalt plant. Thus, after rainy days, more energy is needed to heat and dry humid aggregates (Thives and Ghisi, 2017). In addition, the Brazilian regulations do not include any consideration of the residual RAP binder, only consider tests on the final recycled mixture. A comparison between various mixtures showed that increasing the amount of RAP in asphalt mixtures significantly reduced energy consumption and reduced GHG emissions (Aurangzeb and Al-Qadi, 2014). In an ideal case of a 100% RAP mixture, CO_2 emissions would be reduced by 35% (Zaumanis *et al*., 2016). If used correctly, a reduction of 34% of the final price is estimated in a mixture of 50% of RAP (Kandhal and Mallick, 1998).

Tire Rubber: Recycled Tire Rubber (RTR), from discarded tires, has been used in asphalt by the paving industry since 1960. In Brazil, the law requires a mandatory reverse tire logistics process, which means that producers, importers, distributors, and traders must reintroduce tires into the production chain. The law is one of the reasons for the high use of rubber for tires in the production of asphalt in Brazil. Another reason is traffic: in places with heavy traffic, mixtures with rubber-modified asphalt have greater strength and a longer service life than mixes with ordinary asphalt. Being only 8% more expensive per ton (Catalog of items SCO - RIO, 2017), the life cycle grows 50%, going from 6 to 9 years (Thives and Ghisi, 2017). Brazilian specifications state that at least 15% of the recycled rubber must be added to the asphalt binder to be considered rubber asphalt. Some asphalt manufacturers, mainly in the south-eastern region, have already built several kilometres of pavements with rubber asphalt (CNT, 2017). Thanks to its rigidity, strength, and longer life cycle, it is considered ideal for heavy traffic roads (CNT, 2017).

Warm Asphalt Mixture: The warm asphalt mixture (WMA) is manufactured, applied and, compacted at lower temperatures than the hot asphalt mixture (HMA). This temperature reduction of 20 - 40ºC led to the following classification of asphalt mixtures based on temperature: Hot Mix Asphalt or HMA (190^{o}C - 150^{o}C); Warm mix asphalt or WMA (100^{o}C – 140^{o}C); Half-warm mix asphalt or HWMA (60 - 100ºC); and cold mixes or PCM (0^{o}C - 40^{o}C) (Rubio *et al*., 2012). The WMA temperature reduction is the result of recently developed technologies that involve the use of organic additives, chemical additives, and foaming processes (divided into water-containing and water-based processes). Asphalt foam is made from the addition of water, which increases the volume of the bitumen several times and decreases its viscosity in a short period (Woszuk and Franus, 2017). Although these technologies are quite different, they all aim at the same objectives, that is, lower bitumen viscosity, better surface workability and better level of emission (Rubio *et al*., 2012).

Table 1. Some of the main Products used in WMA

Some of the Products used in WMA			
Foaming process		Chemical	Organics
Water- based	*Water-containing*		
Aspha-Min®, Adversa®	Double Barrel Green, LT Asphalt, WAM-Foam, Low Energy Asphalt, LEAB	Evoterm, Cecabase RT, Rediset, Reivx	Sasobit, Asphaltan B

Some of the benefits of WMA compared to HMA are (Chowdhury and Button, 2008):

- significantly lower production and placement temperatures.
- Lower fuel / energy consumption, reducing fuel / energy costs.
- Less asphalt aging during in plant mixing and placement, thus improving the longevity of the pavement's useful life.
- Reduced thermal segregation in the blanket.
- Decrease in emissions / odours from the mixing plant and during laying.
- Decreased dust production due to low temperatures and shorter heating times.
- Prolonged paving season (like paving during the coldest weather).
- Extended transport distance of the mixture (due to the smaller difference between the ambient temperature and the temperature of the mixture) and, thus, provide expanded market areas.
- Paving in unreached areas.
- Facilitates compaction, which is beneficial for rigid mixtures, RAP mixes, low temperature paving and reduced compaction effort.
- Better working conditions for the plant / paving team.
- Reduced public exposure to emissions.
- Possibility to install it in urban areas.

Despite being originally developed in Europe, the use of WMA still does not occupy a relevant position in many countries of the old continent, with the highest rate in France with 10% of the total production of mixtures. In the USA, technologies have grown more rapidly (Figure 3), WMA's estimated total production was 119.8 million tonnes in 2015, which represented 33% of the country's asphalt mix production (Hansen and Copeland, 2017).

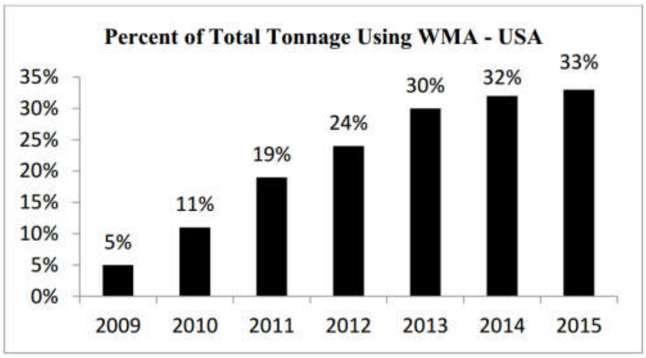

Figure 3. Percent of Total Tonnage Using WMA in USA. (Hansen and Copeland, 2017)

The type of asphalt mixing plants is one reason that explains the increase in the use of WMA in the USA compared to European countries. In the United States, counterflow drum mixing is often used. It is easier to foam asphalt with water in these plants. In Europe, the use of batch plants prevails. The production of WMA using additions in the form of synthetic waxes or chemical additions is possible in these plants without major technological changes (Woszuk and Franus, 2017). In the USA, 88% of WMA production is based on the foaming process (EAPA, 2014). Based on this information, it is possible to conclude that the defoaming process is the most interesting technology from an economic point of view. Pollution due to the high temperatures at which the asphalt mix is produced is a concern for society and for the paving industry. Lowering the temperature means lower fuel consumption and a considerable reduction in emissions. WMA provides a 26% reduction in the impact of HMA on global warming and a 29% reduction in acidification. The consumption of fossil fuel and the formation of photo-oxidant decreased by 25% (Mazumder *et al*., 2016). Table 2 shows the emissions reductions in different countries (D´Angelo, *et al*., 2008). If stricter emission standards were implemented and applied, the WMA would have even greater economic potential.

Table 2. Observed reduction (percent) in emissions with WMA. (D´Angelo *et al*., 2008)

Observed reduction (percent) in emissions with WMA				
Emission	Norway	Italy	Nederlands	France
CO_2	31.5	30-40	15-30	23
SO_2	NA	35	NA	18
VOC	NA	35	NA	19
CO	28.5	10-30	NA	NA
NO_X	62.5	60-70	NA	NA
Dust	54.0	25-55	NA	NA

Theoretical calculations indicate that a temperature reduction of 28°C should result in a fuel economy of 11% (Prowell *et al*., 2012). Due to the different additives and processes, calculating a standard energy saving becomes difficult. According to Chowdhury and Button (2008) in the analysed projects, energy consumption was reduced by 30%-50%. According to Kristjansdottir (2006) it would be reduced by around 30%, D´Angelo, *et al*. (2008) concluded that if Low Energy Asphalt is used, this implies a reduction of around 20%-30%, reaching 50%. Almeid-Costa and Benta (2016) reported that the use of Evotherm for the base layer reduced the energy required by 27%, while Sasobit for the surface layer reduced by 13%. After analysing the energy consumption of Swiss plants, Bueche and Dumont (2012) observed that WMA could save between 25% and 47% of energy compared to hot asphalt plants. Finally, Prowell *et al*. (2012) based on several WMA projects built, reported fuel savings ranging from 15.4% to 77%, where the average fuel economy was 23%. In a Brazilian plant where the cost of fuel represents about 20% of the ton of HMA (Catalog of Items SCO - RIO, 2017), reducing the energy consumed by 30%, the total savings would be around 6%. These percentages are highly dependent on the prices of energy sources, sources that can be natural gas or diesel. Although the WMA promises a significant reduction in energy consumption, the initial costs, in addition to royalties, can discourage contractors. The use of WMA technology requires additives (a recurring cost) and modifications to the asphalt plant, which requires capital investment (Rubio *et al*., 2012). In fact, the initial cost of WMA may be the biggest obstacle to be overcome. This initial cost varies depending on the technology used. For example, WAM-Foam requires modification of the plant to accommodate foaming, which is estimated at US$ 50,000 to US$ 70,000. The approximate cost of the plant modification required for Double Barrel Green WMA technology was quoted at US$ 75,000 and no other material costs are involved. Evoterm does not need major modifications, but the cost of the additive is high (Chowdhury and Button, 2008). Another important point of the WMA, in addition to its ability to reduce temperatures and emissions, is the ability to add greater amounts of RAP as a source of binder and aggregate. This combination is a remarkably interesting and current reason for analysis by researchers and road agencies. This RAP addition point is extremely important, as it can decrease final prices and, therefore, tilt the scale for the use of WMA technologies in detriment of current hot mixes (Oner and Sengoz, 2015). The use of RAP to produce WMA mixtures helps to improve various engineering properties, viscosity, workability, creep deformation, rutting potential, low temperature cracking and fatigue failure. The field performance of these mixtures is also comparable to HMA mixtures. However, due to the lower temperatures of production, it is important to check the susceptibility to humidity, especially for binders aged for a long period (Farooq and Mir, 2017). Finally, a benefit in the execution of paving works, such as workability, can be translated into economic benefits due to the lower need for compaction energy. Some studies indicate a 30% savings in compaction equipment using WMA compared to HMA. (Thives and Ghisi, 2017). According to Kristjansdottir (2006), this benefit could be a greater potential incentive for energy reduction for contractors to adopt WMA.

CONCLUSION

There are numerous environmentally friendly and economically viable techniques. Due to the current state of Brazilian roads, new solutions must be explored and tested. The first conclusion after conducting this study is the lack of information about the characteristics of Brazilian paving works and their performance. Without information, technology becomes difficult to apply and traditional techniques, even when they have disadvantages, continue to be used. It is recommended to create an easy and accessible information network, composed of a national database. Examples like LTPP in the United States should be considered and followed. The second point concerns legislation, handbooks, and standards in force. With a law passed in 2010 that requires recycling, the current paving manuals date from 2006 and have almost no reference to the reuse of materials or the recycling of plants, they are out of date. An update must be made.

Regarding maintenance, the lack of maintenance activities in the bidding process results in functional and economic problems for Brazilian roads in the early stages of the life cycle. The maintenance and long life of a pavement has proven to be the most sustainable practices in the long run. Regarding the use of recycled materials, Brazil generates large amounts of construction waste that could be better used than its disposal in landfills. In the cases of RCA or RAP as base layer aggregates, its use is not limited to low traffic roads, but requires that the material undergo proper control so that it can be used for higher traffic loads. A considerable increase in aggregate recycling plants shows a promising future in this area, but much remains to be done. The Netherlands has rates close to 99%, while Brazil reaches just 20%, according to the most optimistic forecasts. The residual binder contained in RAP and Asphalt Rubber could replace part of the virgin bitumen that contributes almost 50% of the price of the ton of HMA. The use of RAP has low market penetration in Brazil. Correct RAP processing practices, particularly storage and sorting, considerably reduce energy consumption and perform better, resulting in longer lasting floors that result in a more attractive product for contractors. Brazil has the advantage of having discontinuous and continuous plants in similar proportions, which allows an easier adaptation to the WMA foaming process in continuous plants and high use of RAP in batch plants. As to produce asphalt rubber, it is an excellent product in high traffic routes, increasing the life of the pavement. Brazilian legislation established the requirement for reverse tire logistics, which makes the product even more attractive for recycling. Finally, for sustainable production it is essential to adopt and promote the use of WMA technologies. WMA appears as an excellent alternative because emissions are reduced and fuel is saved, in a context of rising fossil fuel prices and stricter environmental protection rules by governments. The possibility of adding more quantities of RAP can mean the final economic advantage. These considerations point to the need to create technical standards, and a national handbook of correct practices, with Japan as a reference (NAPA, 2015), to promote the use of WMA, the different additives, and the plant's adaptations.

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