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Utilization of Synthetic Coarse Aggregate of Calcined Clay in Asphalt Mixtures in the Amazon Region

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Abstract: There are high costs in paving services in the Brazilian Amazon region, mainly due to the lack of coarse aggregate—pebble or crushed stone—in addition to the elevated rainfall and the high geographic expanse of the region. The natural coarse aggregate often used in that region is extracted from the riverbeds a distance no less than 500 km from the major cities. In search of a technical, economic and environmental alternative to work around the problem, using an unconventional material that could replace the pebble or crushed stone, a study was carried out on natural clay, considered an abundant mineral resource, especially in the Amazon Basin. A manual mill was used for this purpose, consisting of four square metal nozzles of dimensions 12.7 mm, 9.5 mm, 4.8 mm and 2.0 mm, used for moulding the wet ribbon clay. After that, firing was carried out at temperatures of 780 °C, 850 °C, 950 °C, 1,050 °C to 1,150 °C. A comparative analysis between conventional hot mixed asphalt—using pebble as coarse aggregate—and that employing synthetic aggregate was made. In a general way, hot mixed asphalt using synthetic aggregate showed excellent results of physical and mechanical properties, in relation to the conventional mixture, mainly at higher temperature of aggregate calcination.

Key words: Synthetic aggregate, calcined clay, asphalt concrete, burning temperature.

1. Introduction

The consumption of coarse aggregate in paving services is characterized by large volumes, corresponding to approximately 60% of the total volume of asphalt concrete. The Amazon region has high costs in pavement constructions, mainly by the lack of natural stone (crushed stone or pebbles), whose availability is far from the main places of consumption. The geological formation of that region largely consists of unconsolidated sedimentary layers of Quaternary and Tertiary period, with surface composed of materials such as fine sand, silt and clay, forming an extensive thick superficial soil, resulting from rock weathering over the years. The coarse aggregate often used in the State of Amazonas (North of Brazil) is the natural pebble, extracted from riverbeds, being transported by barges with a capacity of 1,000 t to 2,000 t, with transport distances between 500 km and 700 km away, to the main consuming centre (Manaus city). By virtue that transportation costs account for approximately 50% of the final product price. For this reason, most of the asphalt coating on site is HMSA (hot mixed sand asphalt) type, more likely to develop permanent deformation, with short life-cycle associated. In search of an alternative and unconventional material that could offer a competitive price in relation to the aggregate now in use, the natural clay was studied, considered an abundant mineral resource in the region, for its own geological formation, given the huge natural drainage system formed by the Amazon Basin. The lightweight aggregate production process of expanded clay, in a rotary kiln, is widely known from the pioneering patent by Ref. [1]. There was a rapid growth of this industry in the U.S. and Europe for decades. According to Ref. [2], however, there are clays that "bloat" and clays that "do not bloat", depending on its constituent minerals and firing. Moore

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et al. [3] reported their experiences with the clay of the State of Texas, stating that when clay minerals are completely dehydrated, generally between 550 ^{o}C and 750 ^{o}C for about 15 minutes, they become chemically stabilized for use as highway construction material. Besides that, the raw material to produce synthetic aggregate does not need to have expansive characteristics. Also, according to those authors, it can be said that any clay having high plasticity, and high compressive resistance when air-dried can be burnt to produce hard, durable synthetic aggregate. The Texas Highway Department established a classification system obtained from the burning of clay [4]. And according to that body, synthetic coarse aggregate can be used in highway works, such as base materials, and in asphaltic and cement concrete.

The Road Research Laboratory reported the production of synthetic aggregate in Nigeria [5], in Guyana, Sudan and Australia [6]. Bunnag and Lerdhirunwong [7] used synthetic aggregate produced in a rotary kiln in ordinary asphalt concrete and surface treatment, in Thailand. These authors compared the pavement built with calcined clay and conventional aggregate (limestone), by monitoring a secondary road on site. The results showed improved service life with higher SRV (skid resistance value) and STD (surface texture depth) of the pavement using synthetic aggregate. Campelo et al. [8] demonstrated, from laboratory tests, technical, economic and environmental viability of calcined clay employment in asphalt mixtures with the natural clay coming from the pottery pole of Iranduba and Manacapuru, in the interior of the State of Amazonas. Cabral et al. [9] conducted studies on the use of synthetic aggregate in asphalt mixtures with raw materials coming from the State of Pará (Amazon region), finding excellent results when compared to the natural coarse aggregate (crushed stone), stating that the synthetic aggregate supports heavy mechanical compaction, according to the results in degradation tests. Cabral et al. [10] reported the use of calcined clay in structural concrete in the State of Amazonas, concluding that the mechanical resistance was similar to that with natural aggregate (pebbles), for the same cement content. This unconventional aggregate, here designated as SCACC (Synthetic Coarse Aggregate of Calcined Clay), can be employed in HMAC (hot mixed asphalt concrete), making it a technical, economic and environmental alternative to be utilized in road services, since the raw material to produce this aggregate is abundant in the Amazon region and always close to the consumer market. The biggest concern in the use of that aggregate is the high rate of absorption that it has. In this context, it is noted that the temperature and time of calcination are variables to be determined in the preliminary stage of production. The temperature has a direct influence on the physical and mechanical characteristics, being a directly proportional variable to the quality of the final product.

1.1 Geological Conditions of the Study Region

The clay minerals commonly used in the red ceramic industry in the study area are found in floodplains and have high plasticity. Nevertheless, there are also low plasticity clays, derived from residual deposits formed by weathering of rocks of the "Alter do Chão" Formation, found on land of higher altitudes; and sandy clays, coming from latosols, used in the construction of landfills, preparation of mortars and production of Portland cement (Fig. 1).

The country sides of Manacapuru and Iranduba have the largest red ceramic pole of the State of Amazonas, and its capital, Manaus city, is the main consumer market. Studies conducted by the Geological Survey of Brazil [11] demonstrated the existence of 4.315 billion cubic meters of clay reserves with great potential for use in the clay industry. Most constitutes of residual deposits resulting from "Alter do Chão" Formation, consisting of quartz, kaolinite, illite/muscovite, smectite and feldspar. The villages referred to are located in a

dissecting plain, representing an important source of clay minerals used in the manufacture of red ceramic. They are generally used to produce tiles, bricks and ceramic art. Fig. 1 shows the geological map of the study area and local soil sampling for the production of SCACC.

1.2 Physical and Mechanical Laboratorial Tests

Several samples of clayey soil were collected from the deposit of a red ceramic industry (Fig. 1). Fig. 2 shows a sample in its natural state and after burning at 850 °C. The procedure adopted for the production of SCACC was to moisten and homogenise the soil by hand, putting it in a mill, producing a "bar" through four distinct square cross section nozzles, cutting it manually forming a wet aggregate with average length of 10 mm.

Then, the aggregates were dried and finally calcined in an electric muffle furnace at temperatures of 780 °C (synthetic coarse aggregate SCA-780 °C), 850 °C (SCA-850 °C), 950 °C (SCA-950 °C), 1,050 °C (SCA-1,050 °C) and 1,150 °C (SCA-1,150 °C) for a period of one hour, after reaching the desired temperature. After this, the furnace was turned off and remained closed until it reached ambient temperature.

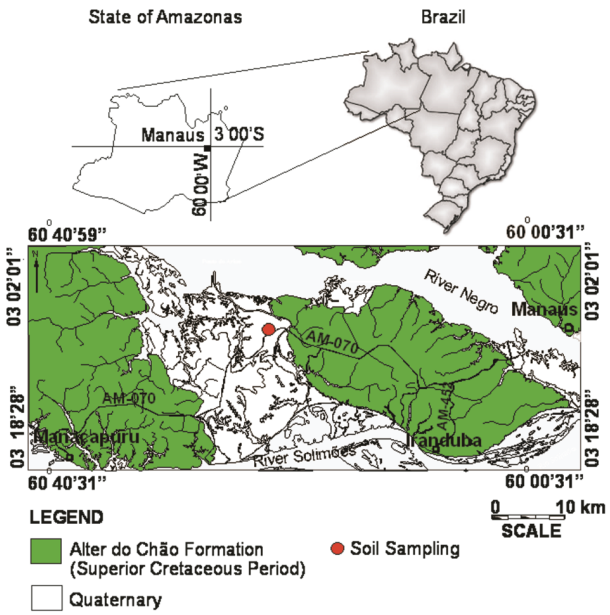

Fig. 1 Geological conditions of the location of raw material study.

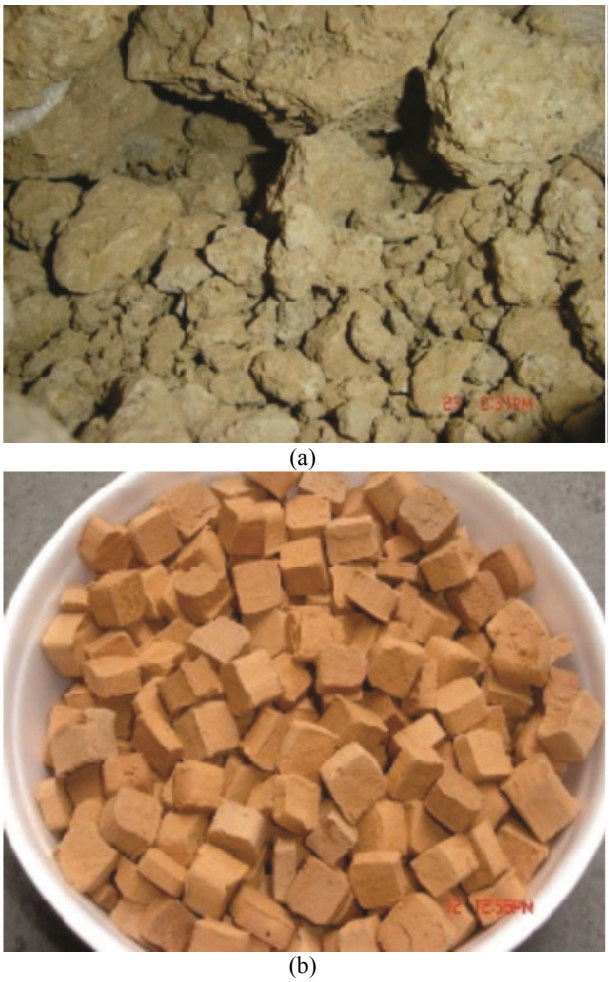

Fig. 2 Production process of SCACC: (a) natural clayey soil, and (b) after burnt at 850 ºC.

Once the pebbles had a maximum diameter of about 12.7 mm, SCACC produced in this research had grain-size fractions corresponding to the pebbles, i.e., dimensions of 12.7 mm, 9.5 mm, 4.8 mm and 2.0 mm. Two different granulometric proportions were adopted for the SCACC (named ACC-1 and ACC-2) and one for the pebbles (such as reference of analyses) for each calcination temperature, based on local experience with the use of these materials in hot asphalt mixtures. Table 1 shows the proportions adopted. The used filler material was Portland cement CP-Z-32, while the AC (asphalt cement) employed was penetration-graded 50/70. After the physical characterization of all the components of the asphalt concrete, the coarse and fine aggregates were set within the "C" range limits of the Brazilian highway

standards, following the conventional Marshall dosage method.

Further, the AC was added in mixtures, adopting the content of 4.5%, 5% and 5.5% for conventional asphalt concrete (with pebbles), and the contents of 6%, 7%, 8% and 9% for the asphaltic concrete made with SCACC. The physical and mechanical mixture parameters were determined, i.e., GMB (bulk specific gravity), TMG (theoretical maximum specific gravity), AVV (air void volume), VMA (voids in the mineral aggregate), VFA (voids filled with asphalt), AVR (asphalt-void ratio), STA (Marshall stability) and FLV (flow value).

The results were plotted in function of the variation of AC content obtaining the characteristic curves of the Marshall test. The OAC (optimum asphalt cement content) adopted for each mixture was those with a AVV between 3% and 5% and AVR between 75% and 82%. After that, a performance comparison between the two mixtures studied was made, both with synthetic aggregate.

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1.3 Results and Discussions

Tables 2 and 3 show the physical and mechanical parameters of each mixture. As expected, the asphaltic concrete made with SCACC consumed more AC, due to the porosity of these aggregates when compared to conventional asphalt concrete. However, as the calcination temperature of these aggregates increased, the AC consumption decreased. For this reason, it can be said that the use of the synthetic aggregate for hot mix asphalt should have a higher calcination temperature than that for use in base or subbase of pavement layers. The TMG values of the mixtures decreased slightly between 850 °C and 1,050 °C, increasing to 1,150 ºC, due to variation in the apparent specific gravity of the aggregates. The bulk specific gravity had little variation. Mixtures with calcined aggregate had lower apparent and theoretical densities when compared to the mix with pebbles.

From Table 2 it can be observed that when firing temperature increased, AVV, VFA, VMA and AVR values decreased, between 850 °C and 1,050 °C, increasing to 1,150 ºC. All these results showed changes in chemical, physical and mechanical behaviour of synthetic aggregate from 1,050 °C.

The mixtures with SCACC exceeded the minimum limit established by Brazilian standards for the Marshall stability, reaching values above 100%, compared to conventional mix to temperatures above

Table 1 Granulometric proportions of used coarse and fine aggregates.

Mixture	% SCACC	% Pebble	% Sand	% Filler
ACC-1	60	0	35	5
ACC-2	55	0	40	5
Pebbles	0	67	28	5

Table 2 Physical parameters of mixtures by Marshall method.

Aggregate	OAC (%)	TMG (g/cm^3)	GMB (g/cm^3)	AVV (%)	VFA (%)	VMA (%)	AVR (%)
SCA-850 °C	8.4	2.10	2.00	4.58	16.91	21.48	76.69
SCA-950 °C	8.0	2.09	2.01	4.06	16.14	20.20	79.89
SCA-1,050 °C	6.0	2.08	2.00	3.99	12.03	16.02	75.08
SCA-1,150 °C	6.0	2.18	2.09	4.18	12.57	16.75	75.05
Pebbles	5.0	2.47	2.38	3.90	11.94	15.84	75.37

Table 3 Mechanical parameters of mixtures cakulated by Marshall method.

Aggregate	STA (kN)	FLV (mm)	ITS (MPa)	RM (MPa)	RM/ITS
SCA-850 °C	10.92	4.22	0.80	2,613	3,267
SCA-950 °C	11.22	4.19	0.90	2,809	3,121
SCA-1,050 °C	15.87	3.11	1.15	4,292	3,732
SCA-1,150 °C	15.28	2.86	1.26	4,767	3,783
Pebbles	6.78	2.83	0.84	3,316	3,948

1,050 °C. The round shape and smooth surface texture of the pebbles contributed to reducing the friction between the particles of these aggregates, resulting in the decrease of shear strength of this mixture. The flow values decreased with the increasing temperature of the synthetic aggregates, having a value close to the mixture with pebble, for the temperature of 1,150 ^{o}C.

Moreover, the mixtures made with SCACC had a stronger structural skeleton than with pebbles, because of better interaction between its components. It was observed that the flow value decreased with increasing calcination temperatures, i.e., mixtures with a higher content of AC demonstrated greater deformation, since this material has a viscoelastic behaviour.

As SCACC densifies itself, reducing its voids, there is a gain in the ITS values. Note that all mixtures had ITS values superior to conventional mix, with exception to that made with SCA-850 °C. A linear proportionality between ITS and RM can be observed. The HMAC made with SCA-1,150 ^{o}C showed ITS and RM values much higher when compared to the others, characterizing very stiff mixtures, with great possibility of developing permanent deformation, with the appearance of cracks. Both values found for ITN and MR at 25 °C are higher than those reported by Cabral et al. [9].

The behaviour of asphalt mixtures regarding fatigue life is another equally important feature. The literature suggests the relationship between RM and ITS as an analysis parameter used to evaluate the behaviour of asphalt mixtures in fatigue life. It is observed that all mixtures prepared with synthetic aggregate showed lower values of the RM/ITS ratio when compared to the conventional mixing (with pebbles), suggesting an improved fatigue life for mixtures with SCACC. This result agrees with the work presented by Bunnag and Lerdhirunwong [7].

Hence, the best temperature for calcination of the synthetic aggregates to be used in hot mix asphalt is between 850 °C and 950 °C, because it aliases lesser amount of open surface pores with an economy in the energy to burn the aggregates.

2. Conclusion

In areas in which there is the lack of stone materials

large scale production of synthetic aggregate of calcined clay in a specific ceramic industry can be considered a technical, economic and environmentally viable substitute. The synthetic aggregate can be calcined at normal temperatures in local potteries for the production of bricks and tiles, i.e., between 850 °C and 950 °C. For base or subbase layer of pavement those temperatures can be lower.

Asphalt mixtures made with synthetic aggregate of calcined clay offer a better fit between its components, when compared to those made with pebbles, favouring mechanical strength gain. Synthetic aggregates of calcined clay, when applied in asphalt mixtures represent a tougher structural skeleton than pebbles, in which the latter is presently more utilized in the State of Amazonas. In concrete asphalt, as the calcination temperature of the synthetic aggregates increases, the use of asphalt cement content decreases due to the crystal phase transformation into an amorphous phase.

It was noted that in SCA mixtures when firing temperature increases physical Marshall parameters values decreased between 850 °C and 1,050 °C and increased at 1,150 ºC, allowing concluding that relevant changes occurred to improve the behaviour of synthetic aggregates. This process causes densification of the ceramic body, closing the existing surface pores in the aggregates.

The results of the RM/ITS ratio allowed inferring that the asphalt mixtures with synthetic aggregates improved the fatigue life, as compared with the mixture with pebbles. This result is consistent with other works cited in the technical literature.

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References

[1] E.S.C.S.I. 1971. *Lightweight Concrete: History, Applications, Economics: Expanded Shale Clay and Slate Institute.* Washington, D.C.

[2] Riley, C. M. 1951. "Relation of Chemical Properties to the Bloating of Clays." *Journal of the American Ceramic Society* 34 (4): 121-8.

[3] Moore, W. M., Van Pelt, S., Scrivner, F. H., and Kunze, G. W. 1968. "Suitability of Synthetic Aggregates Made from Clay-Type Soils for Use in Flexible Base." Texas A&M University, College Station, Texas, USA.

[4] Ledbetter, W. B., Moore, W. M., and Gallaway, B. M. 1971. *A Synthetic Coarse Aggregate Classification System—Final Report*. Texas A&M University, College Station, Texas, USA.

[5] Grainger, G. D. 1951. *The Production of a Low-Grade Aggregate from Black Cotton Soil by Heat Treatment*. Road Research Laboratory, London, England, 1-5.

[6] Whyte, B. W. 1951. "Method of Burning Soil for Road Construction Employed by the Public Works Department, British Guiana." Road Research Laboratory, London, England, 6-15.

[7] Bunnag, S., and Lerdhirunwong, B. 1986. "Application of Calcined Clay as Aggregate for Asphalt Pavement and Surface Treatment." Presented at Australian Road Research Board (ARRB) Conference, 13th, Adelaide, Australia, vol. 13, part 3, Construction, Pavements and Materials, 214-9.

[8] Campelo, N. S., Nogueira, A. C. R., and Silva, J. F. P. 2005. "Production of Synthetic Coarse Aggregate of Calcined Clay in Pottery Pole of Iranduba City for Employing in Road Infrastructure and Civil Construction in State of Amazonas. Study of Technical, Economic, Environmental and Commercial Viability—EVTEC." State of Amazonas Govern Program for support to research in companies. PAPPE/FAPEAM/FINEP. Manaus, AM. (in Portuguese)

[9] Cabral, G. L. L., Motta, L. M. G., Lopes, L. A. S., and Vieira, A. 2008. "Calcined Clay Aggregate: A Feasible Alternative for Brazilian Road Construction." In *Advances in Transportation Geotechnics*, edited by Ellis, Yu, McDowell, Dawson & Thom. London: Taylor & Francis Group, 90-6.

[10] Cabral, E. M., Vasconcelos, R. P., Vieira, R. K., Campelo, N. S., Vieira, A. K., Silva, C. C., and Lima, M. D. 2013. "Calcined Clay Applied in Concrete: Advances in Materials Science Vol. 3." In *Recycling and Reuse of Materials and Their Products*, edited by Thomas S., Sebastian, M., George, A., and Weimin, Y. London, England: CRC Press, 35-52.

[11] D'antona, R. J. G., Reis, N. J., Araújo, I. B., Maia, M. A. M., Rosa, S. F., and Nava, D. B. 2006. *Construction Material Project of the Area of Manacapuru—Iranduba—Manaus—Careiro (Low River Solimões Domain)*. Manaus: CPRM—Geologic Survey of Brazil. (in Portuguese)