HIGH QUALITY CEMENT TREATED CRUSHED STONES

FOR CONCRETE PAVEMENT BASES

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INTRODUCTION

Crushed stones may be considered the most ancient material employed on pavement construction. The employment of hydraulic binders to provide cohesion and increase stability on crushed stones can not be taken as a recent technique of pavement construction, since the great consular roads built during the Rome expansion used stabilization techniques for pavement layers.

A factor of paramount importance for successful use of crushed stones in paving is the good compaction of the material, as state Balduzzi & Bender (1) and Croney & Croney (2); the compaction provides the material with a great bearing capacity concerning the vertical pressures. Although the material does not have good capacity to absorb horizontal stresses if solely well compacted, the employment of hydraulic binders can promote it by changing its original characteristics.

The practice of cement bound aggregates is recognized world wide for the construction of bases for concrete or semi-rigid pavements. Some variations are found in the international terminology to refer to similar materials. For instance, Kosmatka & Panarese (3) use the expression “cement-treated aggregate” for a large range of aggregate kinds. The UK Department of Transport uses the term “cement-bound material” for mixtures from soil cement to lean concrete (2). Another common expression in the English language is “cement-treated gravel”, very clear about the kind of aggregate in question. In France there is the general designation “*graves traiteés aux liants hydrauliques*” and the special expression “*graves-ciment*”.

The employment of the expression “cement treated crushed stone” (CTCS) seems to be very precise on clearly defining the kind of aggregate; actually, the expression does not give precise information about the gradation of the crushed stone (if well graded or open graded). Anyway, the term “treated” must be well understood when employed, because the treatement promoted on the crushed stone matrix is solely the development of links between the aggregates, generating an apparent cohesion in the mixture. When the treatement is employed for soils, the function of the cement will be to create a skeleton where the soil particles are held by mortar and then, fixing these particles, according to Lilley (4) and Kézdi (5).

From the observation of the patterns around the world concerning CTCS mixtures, many differences are found for cement content and mechanical properties requirements. Table 1 was consolidated based on information published by PIARC (6,7) only considering that the kind of mixture would be mandatory gravel or stone, well graded, and cement treated; the above mentioned discrepancies can be observed from the presented data. From the data it is clear that the cement content for the CTCS is generally lower than the common practice for the roller compacted concrete. One important aspect to be taken into account in Table 1 is that in countries like Germany, Spain, France and Norway, requirements for strengths are more severe and this is probably due to the restricted grain size distribution requirements for the material, in opposition to other countries where a wider range for grain distribution is common.

The Brazilian case became interesting to study (one of the motivations for the experiments) due to some inconsistencies found in the recent past on the national standard for CTCS. The cement content usually employed for pavement bases is 4% and the compaction requirements point out for the use of compaction effort below the modified AASHTO energy (1.148 MJ/m^3 instead of 2.439 MJ/m^3); the grain size distribuition is closed and strict. As presented, the patterns show a minimum compressive strength of 3.5 MPa in samples of at least 7 days. As a general belief for the paving professionals, the modulus of elasticity could reach from about 5,000 to 7,000 MPa for field conditions. During the 70’s and 80’s, the CTCS was employed for the construction of several highway and airport runways, aprons and parking areas. Unfortunately, few or no research efforts have been made to understand the mechanical properties of the material better, looking for the improvement of the dosage criteria in order to reach high quality cement treated crushed stones. By the mid-80's on, the use of roller compacted concrete with low cement content takes the place of CTCS due to its better strength properties, gaining that time the preferences from builders and designers of concrete pavements.

This paper presents the results of a research developed in the recent years when the mechanical properties of CTCS were evaluated through the use of up-to-date laboratorial techniques, which allowed the definition of new ways for an ideal dosage of the material. The results obtained had implications on the reconsideration of the CTCS as a good potential material for the construction of high quality bases.

MATERIALS FOR TESTS

Aggregates

Aggregates employed for the performed tests with CTCS were one granite crushed rock, typically found near Sao Paulo city and a hard limestone crushed rock, typically alpine found in Hasli, Switzerland. The petrographic analysis of the aggregates were carried out with 7 kg of each material, using maximum a diameter of 32 mm. The following results were obtained from these analysis:

Granite

All the fractions of the aggregate resulted from a sole rock matrix, and 83% of this rock was crystaline (mainly metagranite) with large fractions of quartz and feldspates and low frequency of mica, chlorites and sulfides; the grains were hard and stiff and weak only if containing too many chlorites; 16% of the rock was composed of very stable and stiff cavernous quartz; 1% of the material was composed of stiff marble; non resistant fractions were up to 1% with some porous stones and up to 4% of weak stones, with micaceous minerals and signs of weakness.

Limestone

All the fractions of the aggregate resulted from a sole limestone matrix, with 7.5% (by weigth) of material sensitive to freezing and thawing actions, porous or even very micaceous.

The grains of the materials presented the following physical properties:

- Aparent density: 2,645 kg/m^3 for granite and 2,637 kg/m^3 for limestone;
- Real density: 2,669 kg/m^3 for granite and 2,694 kg/m^3 for limestone;
- Porosity: 0.3% for granite and 0.8% for limestone.

Hydraulic Binder

Tests with the employed hydraulic binder were carried out by the Research Center of the Swiss Cement Industry (TFB) laboratories in Wildegg, Switzerland. The strength tests were carried out employing cubical samples with results converted to a cylindrical strength reference using a conversion factor of 80%, as suggested by Salami (8).

The mortar was prepared according to the European Normalization (EN 196) and clean German sand with upper diameter of 2 mm and a w/c ratio of 0.5 were used. The selected cement received the denomination "Portlandzement" according to the German standard DIN 1164. The cement had the following characteristics:

- 2-day compression strength: 23.4 MPa;
- 28- day compression strength: 37.3 MPa;
- Setting time: 210 min;
- Stability (Le Chatelier): 1.0 mm;
- Fire loss: 2.7%;
- Non-soluble particles: 0.9%;
- SO_3: 2.8%;
- MgO: 1.7%;
- Minimum water need for cement: 27.5%;
- Density: 3150 kg/m^3;
- Specific Blaine surface: 300 to 340 m^2/kg.

SAMPLES PREPARATION

The aggregates were separated before mixture preparation, according to the following fractions: 0/0.5 mm, 0,5/2 mm, 2/4 mm, 4/8 mm, 8/16 mm and 16/32 mm. These materials were previously remained kept at a temperature of 105 ^{o}C for 24 hours. The CTCS grain size distribuition used was well graded and close to the French standard.

The cement content for the mixture was fixed at 4% by weight for all the samples. The water content on the mixtures was a starting point for preparing the samples; it was necessary to define what the ideal moisture content for this particular kind of cemented material would be in order to improve both resistance and elasticity modulus of CTCS. For this purpose, some preliminary tests were performed to better define the moisture content to be employed, althought several standards around the world specify the optimum compaction moisture as a reference for the moisture content.

The mixtures were prepared first by mixing the aggregate fractions, followed by the cement and finally the water, and this was carried out with the help of an automatic mixer in the laboratory, with 10 kg capacity, which allowed the preparation of enough material for two samples at every operation. The homogenization time was 10 minutes and the material rested about 30 minutes on the mixer plate before compaction.

The compaction followed the AASHTO modified compaction test (9), widely adopted as standard for the CTCS as mentioned on the international literature (4,10,11). An automatized compaction procedure was employed in laboratory, avoiding errors due to humam factors. The cylindrical samples were 101.6 mm diameter and 117 mm high. After compaction, a thin film of cement paste was applied in order to avoid non regular surfaces on top of the samples, specially because full paralelism between top and bottom surfaces are required for the mechanical tests.

The samples cure procedure was quite simple, preserving the material inside the mould following the PIARC recommendation (11). Apparatus for air temperature and air moisture control were used in the cure room, and during all the cure procedures the verified condidions were constant, showing a temperature of 21 ^{o}C and 60% of air moisture.

The homogeneity for the samples was a master line for the performed tests, and the reflection of the care on all the mentioned procedures could be verified by the statistical control of the compaction tests. For 53 identical samples the following values were observed: average moisture content of 4.48% with standard deviation of 0.2% and coefficient of variation of 4.46%; average dry density of 2,230 kg/m^3 with standard deviation of 11 kg/m^3 and coefficient of variation of 0.5 %.

MECHANICAL TESTS

Modulus of Elasticity

The tests to define the elasticity modulus of each sample were conducted statically, before the rupture procedures. The *W+B* German hydraulic servo-controled equipment was employed for the tests, using two *LVDT*'s devices centered on both lateral sides of the samples, with nominal precision of 0.00002 mm, using a measurement length of 50 mm.

For the determination of the elasticity modulus, the maximum stresses level was kept about one third of the ultimate strength, for both tensile and compression tests, according to PIARC (11) recommendation. The conditions for compressive and tensile tests, respectively, were as follows:

- Load application speed: 0.04 MPa/s and 0.004 MPa/s;
- Minimal operation stress: 0.20 MPa and 0.004 MPa;
- Maximal operation stress: 2.17 MPa and 0.297 MPa;
- Number of loading cycles: 5 for both cases;
- Application time for extreme stresses: 30 s for both cases.

Uniaxial Compressive Tests

The same equipment was employed to perform the compression tests. Due to the dimensions of the samples, following the recommendations of PIARC (11), it was necessary to apply correction factors for shape to the results for compressive tests. The ASTM C 39-86 standard (12) was considered for this purpose, in adopting factors for relations length/diameter below 1.8.

Direct Tensile Tests

For the tensile tests, it was necessary to prepare the samples previously by binding metallic 20 mm high cilynders to both top and bottom surfaces. The same equipment was employed for these tests. The tests presented some difficulties discussed as follows:

For the 7-day old samples the received ultimate strength was so low (about 0.16 MPa) that it was impossible to believe in the results. The reason for the low results for the tensile strengths was centered on the fact that the rupture surfaces for all the samples had occurred near their top. According to Raad *et al* (13) the value of the strength obtained during the test can be considered as representative if the rupture surface is near the center of the sample; indeed, Bazant & Cedolin (14), based on the Mechanic of Fractures, stated that this condition is essential to accept the strength result during a direct tensile test.

In the present case, it was clear that the compaction criteria, using five sequential layers in the process, made it impossible for uniform distribution of the compactive efforts along the cylindrical sample, resulting in probable differences between compaction densities along the axis of the sample, as stated by Sidoroff *et al* (15). Obviously, considering the same level of stresses in any plane parallel to the top of the sample, the rupture is induced on the weak plane. In order to clarify this question, two new surfaces were cut at the top and bottom of the sample, 20 mm from the original surfaces. This procedure was satisfactory in terms of the new results achieved, because the new rupture surfaces had occured near the central plane of the samples, and so, was adopted for all the successive direct tensile tests.

Fatigue Tests

The fatigue tests were performed by means of the dynamic split (Brazilian) test. Considering that fatigue tests can take a long time depending on the applied level of stresses, all the tests were performed on samples aged at least 56 days. For this task the recommendations of the Transportation Research Board (16) were followed. The equipment employed for the tests was the Hydropulse servo-controled machine available in the laboratory of the Soil Mechanics Institute of the Federal Swiss Institute of Technology, in Zurich.

The minimum level of load applied during each test was 1 kN. The load was simmetricaly applied on the samples, and the stress-controlled procedure was used, with a constant frequency of 10 Hz.

EXPERIMENT RESULTS

In order to define the ideal moisture content for the mixtures, preliminary tests concerning compressive strength and elasticity modulus were carried out for a fixed cement content of 4% and variations of the moisture content toward the optimal moisture content for the AASHTO modified energy for both types of aggregates employed during the tests.

For both kinds of aggregates, the maximum values for compressive strength and elasticity modulus occurred on the dry part of the compaction curves, about 1.5% below the optimal compaction moisture content. The ideal moiture content for the mixtures was about 4% for the granite stone and 5% for the limestone, greater in the last case mainly due to the effects of the absorption of the aggregate. It must be observed that the degree of compaction of the most resistant mixtures is about 99%, even 1.5% below the optimal moisture content. Due to the change in the moisture content of samples to 1.5% below from the optimal compaction moisture, for example, the granite CTCS showed a growth of 36% on the elasticity modulus (9,500 MPa to 13,000 MPa) and of 27% on the compressive strength (9 MPa to 11.5 MPa).

Modulus of Elasticity

Table 2 presents the results for the elasticity modulus, compressive and tensile strengths. Elasticity modulus was evaluated for ages of 7, 28 and 56-day samples. From those results it is possible to infer that no significant changes occured from 28 to 56 days; for instance, taking the 28-day average value for the secant modulus in compression and deducting from it the standard deviation, this value reaches more than 90% of the 56-day reference value; that means, for practical purposes, there is not a significant improvement.

Compressive Strength

Tests of uniaxial compressive strength were performed for 7, 28 and 56-day samples. Again it can be observed that from 28 to 56 days no significant improvements were found for the compressive strength of CTCS; at 28 days the strength reaches about 97% of the 56-day strength. However, the good resulting values of resistance for the mixtures compacted at 1.5% below the optimal compaction moisture value must be stressed. The rupture generally observed during the compressive tests was columnar.

Direct Tensile Strength

Due to the need to cut samples already mentioned for the direct tensile tests, it was possible to define this property only for samples at 11, 44 and 56 days of age. From those results it is possible to forecast average strength for 7 and 28 days, by linear interpolation, reaching 0.55 MPa and 1.01 MPa, respectively.

Fatigue Behaviour

The fatigue tests were carried out with 13 identical samples using the tensile controlled procedure. The levels of tensile stresses applied allowed a number of cycles from 26 up to 1,559,051. The SN relation obtained from the tests, for the lower limit line was:

$$\sigma_n / \sigma_o = 0.871 - 0.054 \log N \quad (1)$$

where σ_n is the applied tensile stress, σ_o is the ultimate tensile strength and N the number of cycles to fatigue, with multiple R of 0.87.

DISCUSSION

Moisture Content

The observation of the samples fractured surfaces during the tensile strength tests showed that, as a general rule, the fractures had occured at the interfaces of the hardened mortar and aggregates. By analogy with the concretes, considering the lower amount of mortar in the mixtures, due to the lower cement content, the fact could be explained on the basis of Farran (17) studies, where it was verified that the mechanical strength of those interfaces are mainly due to the microtexture of the aggregates. In this case, the stronger links would be present in those points where the fine crystals of hydrated cement fill the irregular surface of the aggregates.

The nature of these links, according to Javelas *et alli* (18), when quartz is present, would probably be attributed to the development of hydrated calcium silicates on the mentioned minerals. However, there are several controversies concerning the nature of the binding resting for concretes, as discussed by Struble & Skalny (19). On the other hand, agreement is found in the literature concerning the fact that the tensile strength of the mortar-aggregate interface is lower than the tensile strength of the mortar. Moreover, the texture of the aggregate had significant influence on the concrete mechanical properties, more than the aggregate nature itself (17,20).

The case study noted that the moisture content of the CTCS plays an important role on the mechanical properties, namely strength and elasticity modulus. In order to better understand this role, thin sections (1/30 μm) of the hardened CTCS were prepared employing two samples containing limestone aggregates, 42 days of age, one of them prepared using the optimal compaction moisture and the other 2% points below that moisture value. The thin sections were submitted to microscopic analysis using both fluorescent and polarized light. Photographs of the thin sections can be found in Balbo (21).

Table 3 presents several characteristics observed on the thin sections and, as general qualitative results, it can be stated that: (i) sample A showed excessive presence of water; (ii) sample B presented more homogeneous mortar density on interfaces and less porosity at the interfaces ,as opposed to sample A; (iii) in sample B the mortar capilarity was cleary lower; (iv) the links between the mortar and the aggregates were stronger in sample B. Based on these results, sample B presented a better apparent dosage and compaction.

Considering the reported results and based on the concrete technology, it was clear that the mixture with lower moisture content is more advantageous: more homogeneous and less porous, with notable improvements for the interface links between mortar and aggregates, and better mechanical properties. These effects, due to variations on the moisture content of the mixtures, could be understood under two different but complimentary points of view.

A greater amount of water on the material, according the compaction theory will cause, from the limit of the optimal moisture content, the decreasing of the mixture density when the voids are filled by water, making the distante between grains larger. On the other hand, due to the greater amount of water in the mixture, the cement grains, will also be farther; and the development of the cement gel takes place exactly towards these grains. In this situation the interpenetration between the developed crystals will be less intense, and more porosity will be found on the hardened mortar. However, the mixture strength is more dependent on the chemical links developed between mortar and aggregates, and implicitly on the growth of the crystals (22).

Through the thin section analysis a higher water content was observed for the mixture having weaker links between mortar and aggregates. The imposed distance for the aggregate grains and cement grains due to the greater amount of water greatly contributed to that situation. It seems that the greater amount of water has not allowed an optmization of the contact between the developed crystals and the aggregates, although the stone matrix had good gradation and was well compacted.

It must also be pointed out that the excessive water in any kind of aggregate stabilization and concretes, along the hydration process, is eliminated from the mortar in direction to the aggregate surface, generating a thin water film on it, avoiding the development of good links between aggregates and the cement developed crystals (17). Such behaviour implies the variation of the moisture content inside the mixture structure, increasing the amount of water from the mortar center to the aggregate surface. As the hydration process goes on, the thickness of the thin water film on the aggregate surface decreases through the generation of new crystals closer to the aggregate surface (18).

From this discussion it is clear that, in spite of the differences between vibration and compaction techniques, there is a limit for the moisture content for aggregate stabilization to reach high strength cement treated aggregate bases. Over this limit, evident losses will occur for the mechanical properties of the admixture and then, for the potential of the cement as a binding material. This limit, according to both mechanical tests and thin section qualitative analysis will be below the optimal moisture content received from simple compaction tests.

Relations for Strengths

Based on the above results some relations can be stated between mechanical strengths of CTCS. The relation for the direct tensile strength (R_{td}) and the compressive strength (R_c) resulted in the following equation:

$$R_{td} = 0.370 + 0.059\, R_c \quad [\text{MPa}] \tag{2}$$

with r = 0,825 for 14 pairs of values. If the relation for the above strengths in terms of a ratio between both values is taken, it will be found that:

$$R_{td} / R_c = 0.10 \tag{3}$$

with standard deviation of 0.012 and coeficient of variation of 12.8%.

The results gotten for indirect tensile strength (R_t) were obtained during the fatigue tests when the definition of the rupture load for one simple application. The average value for seven 56-day samples was 2.34 MPa with standard deviation of 0.35 MPa and coefficient of variation of 15%. From these results it was possible to infer a correlation between direct tensile strength and indirect tensile strength as follows:

$$R_{td} = 0.52\ R_t \tag{4}$$

Actually, considering the little homogeneity of the material in comparison to the concrete, and as a matter of fact that during the split test the fracture plane of the sample is defined by the test arrangement, the above relation is quite far from the same relation for normal concretes of about 0.85.

Substituting equation (4) in equation (2) it is found that:

$$R_t = 0.712 + 0.115\ R_c \qquad [\text{MPa}] \tag{5}$$

Relations for Modulus of Elasticity

According to Dac Chi (23) for design purposes of pavements, elasticity modulus for CTCS in traction or in compression must be considered equivalent, with possible error up to 20%. The relations between elasticity modulus in traction (E_t) and in compression (E_c) currently found are in good agreement with the former results shown by the referred author. For instance, for 28-day samples the ratio E_t/E_c was 0.96 (20 samples with standard deviation of 0.177); for 56 days, the ratio reached was 1.084 (25 samples with standard deviation of 0.222); for the whole set of samples the ratio reached was 1.03 (standard deviation of 0.210). Furthermore, it is possible to extend that statement for any kind of elasticity modulus like in flexion.

The current results also agree with the experimental studies carried by Larsen & Nussbaum (24) when the discussed relation ranged from 0,943 to 1,053 for the case of a well graded crushed stone treated with 5% of Portland cement. It is interesting to point out that in many countries, as in Brazil, it is common to admit that the elasticity modulus of CTCS reaches up to 7,000 MPa if the material is well prepared, compacted and cured. The present results showed that it is possible to achieve much better mechanical properties by controlling the moisture content of the mixture and using coherent compactive effort.

Relation for Elasticity Modulus and Strength

For the search of correlations between elasticity modulus (E) and compressive strength (R_c) 47 couples of values of the secant elasticity modulus in compression and compressive strength were taken, for the ages of 7, 28 and 56 days, for both limestone or granite mixtures obtained during the fifth cycle of loading/unloading. The best received correlations are:

$$E = -5{,}133 + 2{,}549\, R_c - 61\, R_c^2 \quad [\mathrm{MPa}] \tag{6}$$

with multiple R of 0.775, standard deviation of 3,233 MPa, and

$$E = 4{,}617\, (R_c)^{0.5} \quad [\mathrm{MPa}] \tag{7}$$

with multiple R of 0.707, standard deviation of 3,533 MPa.

Fatigue Behaviour

Two classical studies from the international literature concerning the fatigue behaviour of cement bound materials must be pointed out. Larsen and Nussbaum (24) performed studies for three mixtures, defining the fatigue relations for prismatical samples submitted to flexural stresses. From this research it was observed that the bearing properties of the subgrades (in laboratorial simulations) did not have significant influence for the fatigue behaviour during the tests.

Symons (25) worked also employing CTCS with several cement contents. The cylindrical samples employed during the research were submitted to torsional efforts to fatigue. As major conclusions, the author stressed that changes on cement content and on the frequency of loading were, apparently, of lower importance if confronted with dispersion found during the fatigue tests. According to the publication, one possible reason for the dispersion was the dispersion found during the definition of the ultimate strength of the material to define the SN relation of fatigue.

In the current research it was found that the results dispersion are quite related to the heterogeneities of a material such as CTCS. Taking the standard deviation found for the indirect tensile strength for 56-day samples, it is possible to find a range for the value from 1.99 to 2.69, *i.e.*, reaching a relative variation near 35%, showing the difficulties that take place during the fatigue tests.

Concerning the controlled stress procedure, Dac Chi (26) has observed that under this condition the fissuration development is accelerated while the elasticity modulus decreases along the process, then reaching better precision in the rupture definition. On the contrary, using the strain controlled procedure, the dispersion of the test is increased due to the necessary changes of loads during the process.

Regarding the fatigue relation defined in equation (1), on Table 4 a set of fatigue relations for the CTCS collected from the international experience is presented containing the constants **a** and **b** for the several mentioned SN relations (σ_6/σ_0) and also the numerical value for SN relations for 10^6 cycles fatigue life. Only equation 9 on Table 4 refers to a roller compacted concrete with low cement content (120 kg/m^3) employed for concrete pavement bases in Brazil.

Taking a large number of fatigue tests for CTCS, Dac Chi (28) showed that the SN value (σ_6/σ_0) for a million load repetition ranged from 0.50 to 0.59, for the same kind of mixture, emphasizing the found dispersion for these experimental models even working with a great amount of samples. Anyhow, the proposed relation could be adopted for design purposes if using similar mixtures for concrete pavement bases or even in the case of semi-rigid pavements.

IMPLICATIONS FOR CONCRETE PAVEMENT DESIGN

The Brazilian National Department of Roads (DNER) established the cement content for the roller compacted concrete between 80 kg/m^3 to 380 kg/m^3; in the latter case the material is employed as the top layer of the pavement (33). The aggregates to be used are similar to the traditional concrete, *i.e.*, there are no restrictive controls about the grain size distribution as in the case of CTCS. The report refers to recent experiments using a roller compacted concrete with low cement content (85 kg/m^3) when the reached mechanical properties for the material were 8.2 MPa of compressive strength, flexural strength of 1.4 MPa and elasticity modulus of 14,200 MPa (all properties referred to 28-day samples).

As observed in this paper, the dosage criteria adopted for the studied CTCS allowed to reach better results than those suggested by the Brazilian agency for the roller compacted concrete. Recent fatigue studies (34) carried out in Brazil for a roller compacted concrete with cement content of 120 kg/m^3 allowed the definition of a fatigue relation very closed to the equation (1) currently presented, showed by equation 9 in Table 4.

Considering the presented results, it is possible to state that, for practical questions of design there are no significant differences between CTCS and the roller compacted concrete as base layers of concrete pavements; on the other hand, there are several differences between the two materials which can play an important role on costs for the decision makers: while roller compacted concrete requires a concrete mixer plant and CTCS is produced by means of an aggregate mixer, the latter requires a very rigorous control of grain distribution; besides, all the aggregate fractions must be from the same crushed stone; on using CTCS, natural sands are not applied.

Another important question to be taken into account is the need for considering fatigue process on cemented bases under concrete slabs. Balbo (35), using a finite element model for concrete slabs, has shown that using the traditional criteria for the design of concrete pavements, supported by Westergaard solutions, when a single modulus of reaction is applied to take the presence of the cemented base into account, the base thickness could be under-designed, and in this situation, due to its fatigue consumption, hard implications can be imputed for the pavement service life.

CONCLUDING REMARKS

The present study yielded the following main conclusions:

- The control of moisture content on CTCS mixtures is of paramount importance for achieving high quality mechanical properties for paving applications. The moisture content for CTCS base layers construction must be controlled below the optimum compaction moisture by about 1.5% points, on the dry part of the compaction curve. This statement is supported by both the performed mechanical tests and the thin section qualitative analysis.

- On controlling the CTCS dosage, as proposed in the study, it is possible to reach mechanical properties (strengths, elasticity and fatigue behaviour) as the ones typical of roller compacted concretes.

Based on the conclusions, the highway agencies and decision makers must consider aspects like costs and availability of material and construction equipment for a good choice of the ideal kind of cement treated base to be applied on concrete pavement construction. CTCS as a constructive technique, in spite of the recent progresses in the soil and aggregates stabilization field, is still an excellent alternative for the construction of bases for concrete pavements.

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