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Development of a high-performance cement-treated crushed stone for pavement bases

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RESUMO

CARGNIN, A. P. **Desenvolvimento de uma brita graduada tratada com cimento de alto desempenho para bases de pavimentos.** 2023. 254 p. Tese (Doutorado em Ciências) – Escola Politécnica, Universidade de São Paulo, São Paulo, 2023.

Brita graduada tratada com cimento (BGTC) começou a ser utilizada no Brasil no fim dos anos 1960 como base de pavimentos com revestimentos asfálticos sob tráfego pesado, incorporando o conceito do material desenvolvido pelos franceses décadas antes. Todavia, principalmente durante a década de 1980, rodovias importantes como a Rodovia dos Imigrantes (SP-160) e Rodovia dos Trabalhadores (SP-070) apresentaram ruptura prematura por fadiga, poucos anos após a abertura ao tráfego. Tal problema persiste até hoje devido a protocolos deficientes de produção e controle das misturas estabelecidos nas normas brasileiras, bem como à heterogeneidade, porosidade e matriz cimentícia muito frágil decorrentes do baixo consumo de cimento. A pesquisa aqui apresentada buscou melhorias no desempenho da BGTC, através de uma matriz mais homogênea, capaz de aproximar o material a um concreto compactado com rolo sem, no entanto, aumentar excessivamente o consumo de cimento. Para tanto, foram estudadas formas de se obter esse material chamado de BGTC de alto desempenho (BGTCAD) estudando os impactos da granulometria, teor de cimento e adição de sílica ativa emulsionada para melhoria da zona de transição interfacial entre os agregados e a pasta de cimento. Em campo, era necessário medir o perfil de temperatura na base de BGTCAD e verificar seu impacto no empenamento, considerando seu comportamento de placa quando recém-construída, ensejando avaliar seu impacto nas tensões e na durabilidade da estrutura. Observou-se que a BGTCAD proposta nesse estudo (com 5% de cimento em peso e 10% de sílica ativa em peso de cimento) apresenta desempenho superior à BGTC convencional considerando seu comportamento à fratura e fadiga; a resistência à tração indireta da BGTCAD resultou 30% maior do que a BGTC convencional, enquanto o módulo de elasticidade resultou em um aumento de 12% resultando em uma redução da relação modular ($E_{ct,sp}/f_{ct,sp}$) de 35%. A análise de sensibilidade dos fatores de equivalência de carga semiempíricos indicou que a BGTCAD é no mínimo 3 vezes mais durável do que a BGTC convencional. Análises dos dados de temperatura revelaram que diferenciais térmicos ocorrem entre topo e fundo da base, induzindo tensões de empenamento na BGTCAD. Negligenciar tais tensões leva à ruptura por fadiga da base

antes ao final do primeiro ano de exposição ao tráfego para uma estrutura projetada considerando o atual Método de Dimensionamento do Departamento Nacional de Infraestrutura de Transportes (DNIT), que não considera a ocorrência de tensões de empenamento na base cimentada. Em última análise, verificou-se a necessidade de se revisar as normas brasileiras no que se refere aos métodos de produção da BGTC considerando distribuição granulométricas, procedimentos de compactação e controle tecnológico, bem como a necessidade de se atualizar o método de dimensionamento, empregando programas capazes de simular as tensões de empenamento induzidas pelos diferenciais térmicos.

Palavras-chave: Brita graduada tratada com cimento de alto desempenho. Empacotamento de agregados. Sílica ativa emulsionada. Diferencial térmico. Pavimentos semirrígidos.

ABSTRACT

CARGNIN, A. P. **Development of a high-performance cement-treated crushed stone for pavement bases.** 2023. 254 p. Dissertation (Doctorate in Science) – Polytechnic School, University of São Paulo, São Paulo, 2023.

Cement-treated crushed stones (CTCS) started being used in Brazil at the end of the 1960s as base for pavements with asphalt layers submitted to heavy traffic, incorporating the material's conception developed by the French decades earlier. However, especially during the 1980s, important roads like Rodovia dos Imigrantes (SP-160) and Rodovia dos Trabalhadores (SP-070) presented premature fatigue failures a few years after opening to traffic. Such problems remain currently and are related to impaired compaction procedures and weak protocols for mixture control in the Brazilian standards, as well as the material heterogeneity, porosity, and brittle matrix due to the low cement consumption. The research herein presented sought to improve the CTCS performance, through a more homogeneous cementitious matrix leading the material closer to a roller compacted concrete (RCC), without overly increasing the cement consumption. For that matter, it was studied ways of obtaining such a material namely high-performance CTCS (HP-CTCS) studying the impacts of granulometry, cement content and the addition of silica fume emulsified to improve the interfacial transition zone between the aggregates and cement paste. In the field, it was necessary to measure the temperature profile in the CTCS base, to verify if the cemented base could curl, given the slab behavior of newly built CTCS, and assess the impact of such stresses on the material durability. It was found the HP-CTCS mixture proposed in this study (with 5% cement content and 10% Silica fume) presents a better performance than conventional CTCS regarding fatigue and fracture behavior; HP-CTCS split tensile strength ($f_{ct,sp}$) resulted 30% higher than conventional CTCS, while the modulus of elasticity ($E_{ct,sp}$) increased 12%, leading to a modular relationship ($E_{ct,sp}/f_{ct,sp}$) 35% lower. Consequently, the sensitivity analysis on the semi-empirical load equivalency factors indicated that HP-CTCS is at least three times more durable than conventional CTC. Temperature data analysis revealed that thermal differentials occur between the base top and bottom inducing curling stresses in the HP-CTCS. Overlooking such stresses leads to CTCS fatigue consumption before the end of the first year of traffic exposure for a structure designed following the current Method applied by the Departamento Nacional de Infraestrutura de Transportes (DNIT), which

disregards the curling stresses. Ultimately it is necessary to revise the Brazilian standards for the production of CTCS regarding granulometric distributions, compaction recommendations, and technological control, and it is needed to update the design method as well, using software capable of simulating the curling stresses induced by thermal differentials.

Keywords: High-performance cement-treated crushed stone. Aggregate Packing. Silica fume in emulsion. Temperature Differential. Semirigid pavements.