CONCRETE REQUIREMENTS FOR ULTRA-THIN CONCRETE OVERLAYS (WHITETOPPING) FOR FLEXIBLE PAVEMENTS

José T. Balbo & Marcos P. Rodolfo
Escola Politécnica - Universidade de São Paulo

SUMMARY

Whitetopping solutions for old flexible asphalt pavement overlays have been a challange for highway agencies and designers in the recent past years, with special regards to ultra-thin concrete overlays, also called by ultra-thin whitetopping (UTW). Considering the needs of full bond between the UTW and the old asphalt concrete (AC) layer it is clear the impossibility of applying conventional theories for the calculation of bending stresses of such thin slabs. Moreover, UTW demands for high strength concretes in order to hold up more severe flexural stresses than the conventional concrete slabs. This paper deals with the requirements for resistances of a concrete to be employed as UTW, taking as case study square slabs with fixed dimension of 1,20 meters and a dual tire single axle of 100 kN. The study has shown significant differences for stresses due to load position and old asphalt layer thickness; a review of recent literature concerning high performance concrete for paving is presented and confronted with the theoretical results.

RESUMO

Reforçar antigos pavimentos asfálticos com emprego de concreto de cimento Portland tem sido um desafio para órgãos rodoviários e projetistas em anos recentes, em especial no tocante aos reforços ultra delgados de concreto (UTW). Tendo em vista a exigência de aderência plena entre o UTW e a camada de mistura asfáltica existente não é razoável o emprego de teorias convencionais para o cálculo de tensões para estas placas delgadas de concreto; além desse fato, os UTW exigem o emprego de concretos de elevada resistência capazes de suportar níveis de tensão geralmente superiores aos pavimentos de concreto tradicionais. Neste artigo são discutidas as exigências quanto à resistência para concretos a serem empregados em UTW com base em um estudo de caso para placas quadradas de dimensão de 1,20 metros solicitadas por eixos de rodas duplas de 100 kN. O estudo indica sensíveis diferenças entre tensões resultantes em função da posição da carga e da espessura remanescente de mistura asfáltica na estrutura do pavimento; apresenta-se ainda uma revisão sobre resistências de concretos de alto desempenho aplicados em recentes trabalhos de pavimentação, sendo tais características confrontadas com os resultados teóricos apresentados.

1. INTRODUCTION

Reinforcing old flexible pavements with concrete layers, also called by whitetopping, is a technique that deserves to be divided under to majors procedures: the construction of normal thickned slabs over the old pavement (with the employment of traditional solutions for joint spacement and possibly dowells) and the application of thin cement concrete layers (about 100 mm) with more closed joints, defining square shaped slabs.

Actually, in the first case, designers are induced to define thickness solutions for the slabs based in conventional criteria of design and concrete properties and construction methods. Ultra-thin whitetopping (UTW) solutions compels to reconsider those aspects in an overall way. For design aims, for instance, it must be take into account that the dimensions of thin slabs do not allow that the full axle over only one slab; on the other hand, one slab must be able to receive the same amount of wheels over a reduced area.

Construction techniques for urban roads suppose that no dowells are employed as well as it must exist any kind of confining in order to avoid to avoid lateral displacement of slabs. The interface slab/old asphalt concrete (AC) surface deserves also special cures: leveling, cleaning, wetting for reducing asphalt surface temperature, particular concrete vibration technique etc.

The leading point on UTW materials is the choice of the concrete mechanical properties in regarding to the consequences of the reinforcement thickness combined with the traffic loads. It seems to be clear that traditional concrete could not take place on situations like that; also, exclusively steel or organig fiber reinforced concrete are not promising techniques for this purpose.

For UTW, high stregth concrete mixtures are demanded and tests using special kinds of mixtures must be carried out in order to allow the definition of an ideal concrete composition. Special admixtures as water reducers, silica fume, fibers and platicizers could be employed together to achieve appropriate strengths for this particular use of the concrete.

In this paper is presented a theoretical evaluation of stresses for UTW solutions received through the application of a numerical analysis for the reinforced pavement structure. This analysis has allowed to infer some interesting needs for the concrete concerning its strength for the case of UTW solutions.

2. NUMERICAL MODELLING OF UTW

2.1 The Boundary Conditions

The numerical analysis was developed by the employment of the FEACONS 4.1SI, an improved version for the International System of Units of the original computer program FEACONS IV developed by Tia *et al* [1].

This modified version of the software permits to simulate both full bonded and unbonded conditions for concrete pavement layers (surface and base) and was concluded by Prof. Mang Tia from the University of Florida at Gainesville, with strict cooperation of the Pavement Mechanics Laboratory of the University of São Paulo, in August, 1997.

Although the program allows the consideration of load transfer on transversal joints and the use of an edge frictional coefficient to correct the imperfection of Winkler's model for edge nodes, the analysis followed a conservative scheme, without load transfer on joints and no use of edge coefficient.

The analysis consisted on the simulation of a single slab bonded to the old AC layer; other kinds of layer above the asphalt surface of the pavement are assumed as a media like the Winkler's model. Several positions for the loads were firstly analysed, as follows.

2.2 Effects of Load Position

For the study of critical conditions of loading, the dual tyre was analysed for three positions: center, transversal joint and corner of the UTW slab. During these simulations, the doble loading area was unified in a single area, for 1,80 x 1,80 meters slabs for a concrete (elasticity modulus of 28.000 MPa). The asphalt layer was supposed to have an elasticity modulus of 4.000 MPa. The pressure for the loaded area was 639 kPa for a load of 50 kN. For all cases the resting thickness of AC layer was 100 mm and the Winkler's modulus of 50 MPa/m.

For such simulations the finite element mesh was divided into equal distances for the loaded area, definig always equal squares excluding for the opposite transversal joint.

The received results are presented on Table 1.

Table 1 UTW sensitivity analysis for load position

UTW thickness (mm)	Flexural Stresses (MPa)		
	Central load	Joint load	Corner load
50	0,56	1,96	3,39
60	0,83	1,74	3,12
70	0,99	1,55	2,82
80	1,07	1,37	2,55
90	1,10	1,21	2,31
100	1,10	1,07	2,11

From Table 1 it can be inferred that the worst condition regarding the flexural stress for the UTW occurs for the corner load. It is also important to note that, for 100 mm thickness of UTW, the flexural stress approaches half of conventional concrete strength for pavements; in other words, flexural strengths close to 4,5 MPa could be not satisfactory in terms of fatigue behaviour for the UTW.

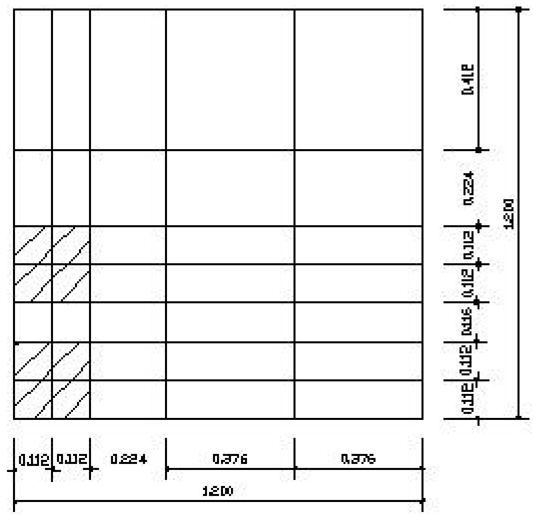
The good condition for central load is due to the fact of AC layer working in full tensile state along its depth. On the other hand, for corner and joint load positions the tensile condition occurs at the upper part of the UTW. Joint loads induce tensile stresses at the upper part of AC layer; for the corner case this condition is compression.

These results are interesting to show the important effect of load position and then to emphasize the needs of a good geometric design for the joints according to the lane width that can change from one kind of road to another.

2.3 Analisys for Corner Loads

Taking the corner position as the critical for the design, it was developed a sensitivity analysis of mesh discretization on stresses. This analysis have allowed the choice of the mesh presented on Figure 1.

Figure1 Mesh adopted for simulations (no scale)



For the following simulations it was taken an elasticity modulus of 3.000 MPa for the AC layer. Indeed, thicknesses from 50 to 100 mm of the asphalt mixture layer were taken. Slabs considered in this study were 1,20 meter-sided squares.

On Table 2 are presented the received results from these simulations in terms of maximum flexural stresses for both layers (UTW and AC). On Figures 2 and 3 are presented curves related to Table 2.

Table 2 Flexural stresses for UTW (underlined) and asphalt mixture layer

AC (mm)	UTW (MPa)					
	50	60	70	80	90	100
50	7,40 -5,12	6,48 -4,88	5,33 -4,24	4,47 -3,69	3,74 -3,17	3,19 -2,76
60	6,28 -3,88	5,67 -3,92	4,81 -3,58	4,06 -3,18	3,45 -2,80	2,98 -2,48
70	5,74 -3,13	4,99 -3,15	4,28 -2,96	3,67 -2,71	3,19 -2,46	2,76 -2,21
80	4,96 -2,34	4,34 -2,47	3,79 -2,42	3,33 -2,31	2,91 -2,13	2,55 -1,95
90	4,27 -1,71	3,79 -1,93	3,39 -1,99	3,00 -1,94	2,65 -1,83	2,34 -1,71
100	3,71 -1,24	3,35 -1,50	3,01 -1,61	2,69 -1,61	2,40 -1,57	2,22 -1,54

Figure 2 Flexural stresses for UTW as a function of UTW thickness and AC thickness

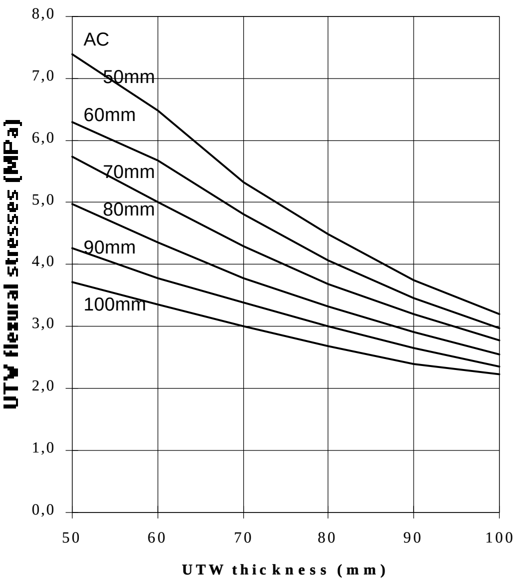
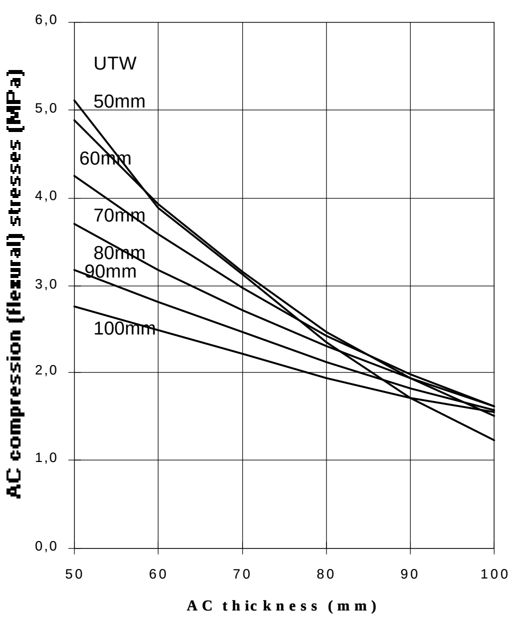


Figure 3 Flexural stresses for AC as a function of AC thickness and UTW thickness



From Figure 2 it can be inferred that the needs of strength for the Portland cement concrete (PCC) increase as the thickness of PCC. As will be detailed foward, the AC thickness is a limitant factor for the concrete strength required for the UTW.

Figure 3 shows that for AC thickness from 80 to 100 mm little variance for the stresses on AC is found. In fact, is was verified changes of 30%, 17% and 5% on AC stresses for AC thicknesses of 80, 90 and 100 mm, respectively.

3. STRESS ANALYSIS

The UTW solution is conceptually an alternative for reinforcing old flexible pavements which suposes, before anything else, a long endurance service life. In this way it could be forecasted for the coming years performance evaluations of in-service UTW in order to define its behaviour under the serviceability point of view.

As a starting point, in the paragraphs bellow, is presented a fatigue analysis based on traditional experimental models for fatigue failure of plain concrete. Nowadays, at least this kind of analysis should be done for the UTW but based on particular models for the kinds of high strength concrete mixtures employed for its construction.

Taking the PCA fatigue model for concrete pavements for the case of *high volume roads*, it could be used the design criteria of unlimited number of load applications. In such situation, it is needed the employment of a concrete with modulus of rupture at least twice the flexural stress of design.

Concerning urban roads, it could be fixed a number of load repetitions of 10^7 as a large endurance criteria, depending on the road characteristics. Moreover, it can be applied the *zero maintenance design* procedure proposed by Darter [2], when the allowed number of load applications to failure (N) is expressed as a function of the flexural stress (σ_f) and the modulus of rupture (MR) by:

$$\log N = 16{,}61 - 17{,}61\ (\sigma_f / MR)$$

Based on the hypothesis above including the results for stresses already presented (Table 2), needs for UTW concrete strengths are condensed on Table 3.

Table 3 Concrete strength needs for the case study

AC thicknes s (mm)	UTW thicknes s (mm)	PCA model (MPa)	Darter model (MPa)
< 70	< 90	8,12 to 14,80	7,44 to 13,55
< 70	≥ 90	5,96 to 7,48	5,46 to 6,85
= 70	50 to 90	6,38 to 11,48	5,84 to 10,51
80 and 90	< 90	6,00 to 9,92	5,50 to 9,08
= 100	50 to 70	6,02 to 7,42	5,51 to 6,80

Only for 25% from the 36 cases presented on Table 2 would be possible the employment of concretes under 6,0 MPa flexural strength, according to the PCA model for unlimited number of load applications. This condition is strictly found to minimum thickness of AC of 70 mm and some cases os UTW thickness from 80 to 100 mm.

Taking then 6,0 MPa flexural strength as a minimum value for the case study, it could be called as maximum strength requirement for UTW the values ranging from 7,5 to 15 MPa observed on Table 3 with regard to situations of UTW thicknesses bellow 90 mm and simultaneously AC thicknesses bellow 70 mm. Otherwise, recent American experience [3] speaks out about an AC thickness of 75 mm as the "minimum recommended as a base".

4. Special Concretes for UTW

Taking the experience of Shah [4] regarding the employment of fibers (glass, stell and polypropylene) for concretes, it seems to be clear that the amount up to 1% by volume of fibers almost do not have influence on the tensile strength of the matrix. The gain of resistance will occur in significative way for amounts greater than 2% by volume.

Then, the employment of such fibers exclusively, without other admixtures, to reach high strength concretes must be put in discussion under an economic point of view. Although some publications shows a good achieving of strength by the employment of fibers, it could not be taken as a general rule.

For instance, Grondziel [5] presents results for a stell fiber reinforced concrete (350 kg/c.m. of pozzolanic cement and w/c ratio of 0,46) with a fiber content of 60 kg/c.m., when the flexural strength reached 7,3 MPa (28 days), a good value in comparison to the reference concrete (5,5 MPa). These results must be taken with some reserve once the aggregate distribuition used for the concrete was very well graduate with maximum diameter of 16 mm.

An interesting experience with steel fibers for concrete pavements applied to urban roads is presented by Johnston [6] in the city of Alberta, Canada. The steel fiber reinforced concretes (approximately 300 kg/ c.m. of cement and 100 kg/c.m. of fly ash) containing amounts from 40 to 80 kg/c.m. of several types of stell fibers (0,5 to 1%). The flexural strengths reached from 4,7 to 5,7 MPa (28 days) with an isolate case of 6,8 MPa.

An urban road UTW experience conduced in Iowa [7] employed a concrete mixture with 298 kg/c.m. of cement type I (according ASTM standard), 56 kg/c.m. of fly ash and admixture of 2,6 ml/kg of water reducer. The 28-day flexural strength was about 4,6 to 4,8 MPa in such case.

From the Kentucky experience [8] in some urban roads is given the results of another special kind of concrete composed by 475 kg/c.m. of cement type I (ASTM), 50% of coarse aggregate (crushed stone) and 50% fine aggregate (natural sand) by volume, water reducer in an amount of 0,98 ml/ 100 kg of cement and 1,78 kg/c.m. of synthetic fibers. The flexural strength reached 5,23 MPa in 24 hours and 7,07 MPa in 28 days.

Concerning the achievement of resistance in early ages, Hallin [9] prepared a paper showing the international experience on fast track concrete from where it can be taken some Japanese concretes. For several cases in Japan, for UTW thicknesses of 50 and 60 mm, the strengh reached by 24 hours was about 3,5 MPa.

Latex modified concrete (polymerer) have been extensively used in U.S.A. for bridge decks and overlays. Surveys showed that the concrete strength for several mixtures, obtained from cores, ranged from 3,9 MPa to 4,5 MPa [10]. According to one manufacturer [11] of this kind of admixtures, it would be possible to get more resistant concrete mixtures, when shows a modified latex concrete with 7,03 MPa of flexural strength by 28 days (with the amount of 15% of the admixture by weight of cement), when the reference concrete presented 5,45 MPa of flexural strength.

As presented by this short review, there are a great number of options to prepare a special concrete in terms of flexural strength. For the future development of UTW technique it will be always a challange for builders to manufacture high strength concretes in order to reach the design requirements. UTW for sure opens a big door to research on concrete technology.

CONCLUSIONS

UTW solutions for reinforcing old flexible pavements can require concrete flexural strengths ranging from conventional concretes (4,5 to 5 MPa) to very high strength concretes (more than 10 MPa). This great variance will be found depending on the kind of road and on the heavy traffic volume.

Due to the large possibilities for concrete mixtures, it seems to be logical that characteristics such as elasticity modulus and fatigue behaviour of each particular kind of concrete must be subjects of future studies once structural analysis and UTW rational design are very dependent on it.

Concerning the special concretes for UTW, it must be considered that not least the final strength is important; moreover, to be well acceptable as reinforcement technique, im most cases, concretes for UTW must reach early convenient strengths for opening to traffic.

The special concretes produced merely with fibers as admixtures can not be suitable in several situations. It seems to be more interesting concretes with admixtures "cocktail" for the gain of strength, specially in early ages.

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