19 Construction of an Ultra-thin continuously reinforced Concrete Pavement

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ABSTRACT
An Ultra-Thin Continuously Reinforced Concrete Pavement (UTCRCP) is a composite structure that makes use of a high strength fibre-reinforced concrete. Originating from Europe, the South African National Roads Agency Ltd (SANRAL) embraced the principles of UTCRCP and developed the technology further to suit local requirements and environment. The use of UTCRCP is intended as an alternative rehabilitation option by providing a thin 50 mm layer of high strength, flexible, concrete constructed as a durable cover on top of existing distressed pavements. During February 2010 the first full scale UTCRCP section was successfully completed on National Route 1 in the Western Cape, where it was constructed as a 4.3 km long truck crawling lane between the Huguenot Tunnel and the Huguenot Toll Plaza. This paper provides a brief background to the developments of UTCRCP in South Africa and discusses in more detail the design processes that were followed for the construction of the UTCRPC truck crawler lane. Whilst complying with strict tolerances and riding quality requirements, the UTCRCP truck crawler lane on the N1 was entirely constructed by manual labour and utilisation of labour and optimisation of the construction process is discussed. A limited economic analysis of the UTCRCP is also included and potential future applications of UTCRCP on heavily loaded pavements are discussed.

INTRODUCTION
The use of Ultra-Thin Continuously Reinforced Concrete Pavement (UTCRCP) as a rehabilitation option for heavily loaded pavement structure is a recent development promoted by SANRAL. Various research projects and test sections have been completed since 2005. The first full scale implementation of UTCRCP, i.e. the reconstruction of a truck crawling lane at the Huguenot Tunnel on National Route 1 near Cape Town, was successfully completed during 2010. Approximately 17,500 m2 of UTCRCP was constructed. By successfully implementing the new and innovative technique of UTCRCP it was demonstrated that it is practically possible to implement UTCRCP on a large and commercial scale. The objective of this paper is to provide an overview of the design and production processes followed for the construction of this UTCRCP truck crawling lane. The specifications for the construction of this UTCRCP were to a large extent already developed by SANRAL and these were only refined for the truck crawling lane. This resulted in the design process focussing more on the optimisation of the concrete mix design, using the specific material components available, and streamlining the construction processes and techniques to suit this larger scale implementation of UTCRCP. A brief background on the developments of UTCRCP in South Africa is provided, followed by a more detailed discussion of the design and production processes. The technical background to UTCRCP and the structural design thereof is not the subject of this paper and references for this are provided. The paper also discusses the labour utilisation for the construction of UTCRCP and some economic aspects are also considered.

DEVELOPMENT OF UTCRCP IN SOUTH AFRICA
UTCRCP is an implementation of Strain Hardening Cement-based Composites (SHCC) in the field of pavement engineering. UTCRCP consists of a high strength concrete mix containing steel fibres and a continuous steel reinforcement mesh in the centre of the layer. The concept of UTCRCP originates from Europe where it has been applied on a limited scale as industrial flooring and for rehabilitation of surfacing layers on steel bridge decks (Braam, Buitelaar and Buitelaar, 2004). Due to the ageing road network in South Africa major investments into rehabilitation and structural strengthening of road pavements are increasingly required. The development of UTCRCP in South Africa has been spearheaded by SANRAL with the objective of developing a new, innovative and cost-effective pavement repair strategy that meets the demands for future investments in infrastructure by road authorities in South Africa. The development of the UTCRCP in South Africa and associated design procedures are described in more detail elsewhere (Kannemeyer et al., 2007; Kannemeyer et al., 2008). Extensive laboratory testing on UTCRCP was carried out previously by the University of Pretoria for SANRAL and various pilot projects were implemented, most notably the construction of UTCRCP test sections and a truck screening lane at the Heidelberg Traffic Control Centre on National Route 3. These test sections were also subjected to extensive research by SANRAL, using inter alia the Heavy Vehicle Simulator of the CSIR and the MLS10 of MLS Test Systems. During December 2008, a road construction contract entitled “Rehabilitation of National Route N1, Section 1, between Huguenot Toll Plaza (km 55,4) and Klip River (km 68,2) excluding the tunnel” was awarded to Martin & East / Jansen Tarmac JV by SANRAL (Contract NRA N001-010-2008/2). The consulting engineering services contract for the design and supervision of this road rehabilitation project was awarded a year earlier to PDNA Consulting Engineers / UWP Consulting JV. Part of this rehabilitation project was the reconstruction of a 4.3 kilometre long downhill truck crawling lane using UTCRCP. The possible applications of UTCRCP are however not limited to rehabilitation of distressed and heavily loaded sections of the national road network. Various other heavily loaded pavements for which UTCRCP can potentially be considered as a long-lasting and low maintenance top layer are as follows:

- Intersections with heavy stop/start movement;
- Weighbridges and truck inspection stations;
- Solid waste stations and disposal sites;
- Warehouse and distribution centres;
- Airport pavements; and
- Container terminals.

DESIGN PROCESS
Requirements N1 truck crawling lane
The current traffic volume on the section of National Route 1 at the Huguenot Tunnel is in the order of 12,000 vehicles/day, of which up to 20% are heavy vehicles. This makes it one of the highest trafficked and heavily loaded sections of road in the Western Cape. The UTCRCP as constructed on this section of National Route 1 is a long lasting pavement designed to carry the estimated future traffic loading of 40 million E80’s over the next 25 years, with minimal maintenance during its service life. Structural design of UTCRCP’s is not the subject of this paper and is in part covered elsewhere (Strauss et al., 2007).

Specifications
Following the extensive research as referred to above, standard

specifications for UTCRCP were developed by SANRAL. These specifications are currently in the form of a "standard" supplement (Section B7700) to the Standard Specifications for Road and Bridge Works for State Road Authorities (COLTO, 1998). These specifications are subject to continuous further improvements and amendments as experience is gained with further implementation. The current specifications prescribe, inter alia:

- Material requirements;
- Concrete mix requirements;
- Mix design process;
- Requirements in terms of manufacturing, placing and compacting the concrete;
- Texturing and curing;
- Trial sections;
- Construction tolerances; and
- Quality control and workmanship.

Mix Constituents and Proportions

Based on the abovementioned specifications, the mix design of the concrete for the UTCRCP truck crawling lane at the Huguenot Tunnel was not a mix design in the true sense. The specifications provided by SANRAL contain a breakdown of the constituent components, as well as their proportions (see Table 1).

Table 1: Mix proportions for UTCRCP concrete mix

Item	Concrete mix component	Proportion per m3
1	Cement	480 kg
2	Fly Ash	87 kg
3	Condensed Silica Fume	72 kg
4	Stone (6.7mm)	972 kg
5	Water	175 kg
6	Sand	684 kg
7	Super-plasticizers: Chryso Premia 100 or similar approved [l/m3]	4 l
8	Chryso Optima 100 or similar approved [l/m3]	2.4 l
9	Polypropylene Fibre	2 kg
10	Steel Fibre (30 mm hooked fibre)	100 kg

Due to the thinness of the UTCRCP, i.e. 50 mm, it is necessary to use aggregate with a lesser nominal maximum aggregate size (NMAS) than what is normally used for concrete in conventional applications. The NMAS of aggregate for UTCRCP is 6.7 mm. Specific properties of the stone are specified, one of which is Flakiness Index (FI; < 35%). Burger, Ebels and Brink (2010) found that the flakiness index has a distinct effect on the strength of the concrete. Based on comparative testing using crushed hornfels rock with a FI of approximately 30% and crushed granite rock with a FI of less than 10% they recommend to use 6.7 mm stone with an FI as low as possible and an Average Least Dimension (ALD) a high as possible. This results in very cubicle stone particles and superior strength of the concrete. It is recommended that the current specification be amended accordingly. The steel fibres are standard cold-drawn steel wires with deformed hooked ends. The minimum length of the fibres is 30 mm while the minimum diameter is 0.5 mm. Although in terms of length a minimum is specified, it is not recommended to use much longer steel fibres, because this negatively influences the workability of the mix. The minimum tensile strength of the steel fibres is 1000 MPa. The steel fibres need to comply with ASTM A820-01 "Standard Specifications for Steel Fibers for Fiber-Reinforced Concrete". These fibres are not locally produced in South Africa, but are available from local importers. The availability is however subject to certain lead times. The specifications recommend a combination of three fractions of sand in order to be able to more accurately control the combined grading. This specified combined grading is based on the results of the research and pilot project phases and is shown in Table 2.

Table 2: Required sand grading

Sieve	Sieve size	%-Passing
1	2.36 mm	100
2	1.18 mm	75
3	0.600 mm	50
4	0.300 mm	14
5	0.150 mm	2.5
6	0.075 mm	<1

It is noted that dry sand fractions with an accurately controlled grading are not readily available. Processed sands for the glass and foundry industry provide a solution, but are significantly more expensive than natural or manufactured sand normally used in the building industry. These cost aspects are discussed later.

Concrete Mix Properties

The required concrete mix properties are also specified in the standard specifications as follows:

- Characteristic 28-days Compressive Strength: min. 90 MPa – max. 120 MPa;
- Characteristic 24-hour Compressive Strength: min. 40 MPa;
- Flexural Strength: min. 10 MPa; and
- Energy Absorption for 25 mm deflection: min. 700 Joules.

The compressive strength is based on the standard concrete text cube method as specified in Method D1 of TMH1 (CSRA, 1986). The flexural strength (or Modulus of Rupture) is based on testing beam specimens (SANS Method 5864). Both the compressive and the flexural strength are determined on concrete mixes with the fibre reinforcement, however, without the steel mesh. In order to test the complete system as used in UTCRCP, i.e. fibre-reinforced concrete with steel mesh reinforcement, a modified version of ASTM C1550-05: "Standard test method for Flexural Toughness of Fiber Reinforced Concrete (using centrally loaded round panel)" is prescribed. For this test laboratory test specimens are made using the concrete and mesh that will be used in the construction of the UTCRCP. The modification is related to the size of test specimens, i.e. circular panels of 600 mm in diameter (standard size is 800 mm diameter). The panel test, as shown in Figure 1, is used for the calculation of the energy absorption (flexural toughness).

Figure 1: Testing of circular panels for energy absorption determination, modified ASTMC1550-05 test

Mix Design Phases

The mix design as prescribed in the standard specifications and as used for the construction of truck crawling lane on National Route 1 at the Huguenot Tunnel may be divided into three phases as follows:

- Laboratory testing for the purpose of selecting the mix components, determining the optimum mix proportions and the optimum water-cement factor (w.c.f.). Only compressive strength and flexural strength tests are carried out at this stage on specimens of fibre-reinforced concrete, but without the steel reinforcement. Also the concrete mix workability (concrete consistency) is tested;
- Testing of energy absorption of the proposed concrete mix; Following the first phase of laboratory testing, the proposed concrete mix (optimum mix proportion and w.c.f.) is used to test the properties of the UTCRPC system, i.e. fibre-reinforced concrete with steel mesh. Should the proposed mix not meet the energy absorption requirements, further refinement of the concrete mix is necessary (first phase testing); and
- Construction of a trial section (see Figure 2) when the proposed mix design meets all the requirements of the specification. A trial section is constructed in order for the contractor to demonstrate his capability to construct the UTCRPC in accordance with the specifications.

More specific information regarding the mix design process of the UTCRCP used on National Route 1 at the Huguenot Tunnel is discussed elsewhere by Burger, Ebels and Brink (2010) and is not repeated here.

Figure 2: Construction of UTCRCP trial section for the truck crawling lane on N1 (off site section)

PRODUCTION PROCESS

The production process as adopted by Martin & East / Jansen Tarmac JV for the construction of the UTCRCP truck crawling lane at the Huguenot Tunnel on National Route 1 can be divided into the following main activities:

- Construction of asphalt interlayer;
- Pre-mixing and batching of mix components;
- Site preparation, formwork and steel fixing;
- Mixing of concrete;
- Placing and compacting; and
- Finishing of surface.

Each step of the production process is discussed in more detail in the following sections.

Construction of Asphalt Interlayer

As mentioned above, the UTCRCP is constructed as a composite system with a 30 mm asphalt interlayer followed by the 50 mm UTCRCP. The interlayer serves the following purposes:

- In order to meet the stringent thickness tolerances for the UTCRCP (Dmax: +/- 8 mm, D90: +/- 5 mm and Dave: +/-0.5 mm) the level and grade of the substrata on which the UTCRCP is constructed needs to be very consistent. The correct construction of an asphalt interlayer ensures that these stringent thickness tolerances can be met;
- The UTCRCP acts as a flexible layer under the influence of heavy traffic loading, although it is constructed using concrete. Also, climatic influences (shrinkage and expansion resulting from temperature gradients) result in movement of the UTCRCP. The asphalt interlayer ensures a proper bond between the UTCRCP and the sub-layers of the pavement structure and prevent delamination;
- The asphalt interlayer reduces stress concentrations in the UTCRCP resulting from point loading on a stiff substrate (i.e. an old stiff and brittle asphalt layer or a stiff cement stabilised subbase); and
- The asphalt interlayer provides a good working surface to set and fix the formwork and fix the steel reinforcement mesh (steel mesh is fixed to the working surface, as discussed later).

The asphalt interlayer for the truck crawling lane was constructed using a fine continuously graded asphalt mix (COLTO, 1998) with a high design binder content of 7.2 % (m/m) resulting in a air void content (VIM) of 1.5%.

Pre-mixing and Batching of Mix Components

The contractor pre-bagged all dry mix components in a storage shed at the contractor's site camp. The reason for this was two-fold, i.e. (a) to allow better control of component ratios by pre-mixing in a controlled environment and (b) to reduce the complexity of the actual mixing of the concrete on site.

A number of the dry cementitious mix components, i.e. fly ash, condensed silica fume and part of the cement, as well as the polypropylene fibre, were pre-mixed in the correct proportions by the supplier in Gauteng Province and supplied in bags to the site. This pre-mixing did not only serve a practical purpose, but also resulted in a better dispersion of the fly ash and condensed silica fume in the mix, resulting in higher strength and better quality concrete mix compared to adding these various components together in one concrete mixing process.

All dry components were measured off and pre-bagged. Where possible bags with a mass as supplied were used, supplemented by bags with a mass weighed off where required. The number of bags from each component required to produce one batch of concrete (approximately 0.33 m3) were packed in bulk bags. These bulk bags therefore contained the stone, sand, pre-bagged cementitious material, including polypropylene fibres and steel fibres (see Table 3). The bulk bags were packed sequentially in reverse, i.e. the components that were to be added last to the mixer (steel fibre) were packed first and the components that were to be added first to the mixer (stone) were packed last (last in, first out: LIFO). The ad-mixtures (super-plasticizers) were measured off in bottles (off site) in the right quantities for one batch of concrete for addition to the water just before mixing.

Table 3: Contents of bulk bag for one batch of concrete (app. 0.33 m3)

Item	Component	No. of bags
1	Stone	10 bags of 32.1 kg (weighed)
2	Sand (mill feed)	6 bags of 25 kg (supplied) 1 bag of 17 kg (weighed)
3	Sand (1.2 – 2.4 mm fraction)	1 bag of 40 kg (supplied) 1 bag of 18.7 kg (weighed)
4	Cementitious components (fly-ash, condensed silica fume and part of cement, polypropylene fibre)	3 bags of 37.1 kg (supplied)
5	Remainder of Cement	2 bags of 50 kg (supplied)
6	Steel fibre	1 bag of 20 kg (supplied) 1 bag of 13 kg (weighed)

Site preparation, formwork and steel fixing

Steel square tubing (50 x 50 mm) was used as side forms for the construction of the UTCRCP truck crawling lane. The square tubing also served as rails for the rotating oscillating screed for compaction and final levelling (see Figure 3, left). The square tubing was fixed to the underlying asphalt interlayer by means of conventional nail-in anchors. It is noted that the square tubing showed a certain amount of movement resulting from climatic influences, even when fixed to the underlying layer. It is therefore recommended to place and position the square tubing in advance, but to only finally fix limited sections of the placed square tubing directly prior to placing the concrete.

The steel reinforcement consisted of sheets 2.4 m by 4.0 m in size with an aperture size of 50 mm (transverse) by 100 mm (longitudinal). The bar diameter is 5.6 mm (Ref 587). The aperture size of the steel reinforcement sheets used for UTCRCP is smaller than the standard size apertures for 5.6 mm reinforcement sheets. The steel reinforcement sheets for UTCRCP therefore need to be purpose-made. This adds to the costs of the steel reinforcement, but the availability is more critical. The fact that the reinforcement sheets need to be purpose-made adds to the lead times for supply.

In the case of the truck crawling lane the reinforcement sheets were placed with the shorter dimension in the longitudinal direction, because the specified lane width of 4 metres matched with the longer dimension of the sheets. Longitudinal overlap is achieved by fixing two adjoining mats together. For the purpose of facilitating overlapping the sheets in longitudinal direction, the last transverse steel bar on each sheet was left out while producing the sheets in the factory. This limits the thickness of the reinforcement at the positions where the mats overlap to two bars thick (see Figure 3, right). This is critical because the UTCRCP layer is only 50 mm thick and the cover on the reinforcement sheets is therefore only (50 – 2 x 5.6) / 2 = 19.4 mm. Introducing a third bar thickness at the position of any sheet overlap would have reduced the cover on the reinforcement even further, which is not desirable.

Figure 3: Steel square tubing used as formwork and rail (left); mesh overlap only two bars thick (right)

The reinforcement sheets were secured in place (fixed) using two items: plastic spacer blocks and steel T-pieces. The spacer blocks ensure that the reinforcement sheet is positioned exactly in the middle of the UTCRCP layer and also prevent any downward movement of the sheets during placing of the concrete. The steel T-pieces hook over the reinforcement and are fixed to the underlying asphalt interlayer using standard wall plugs and prevent any upward movement of the sheets. This is illustrated in Figure 4.

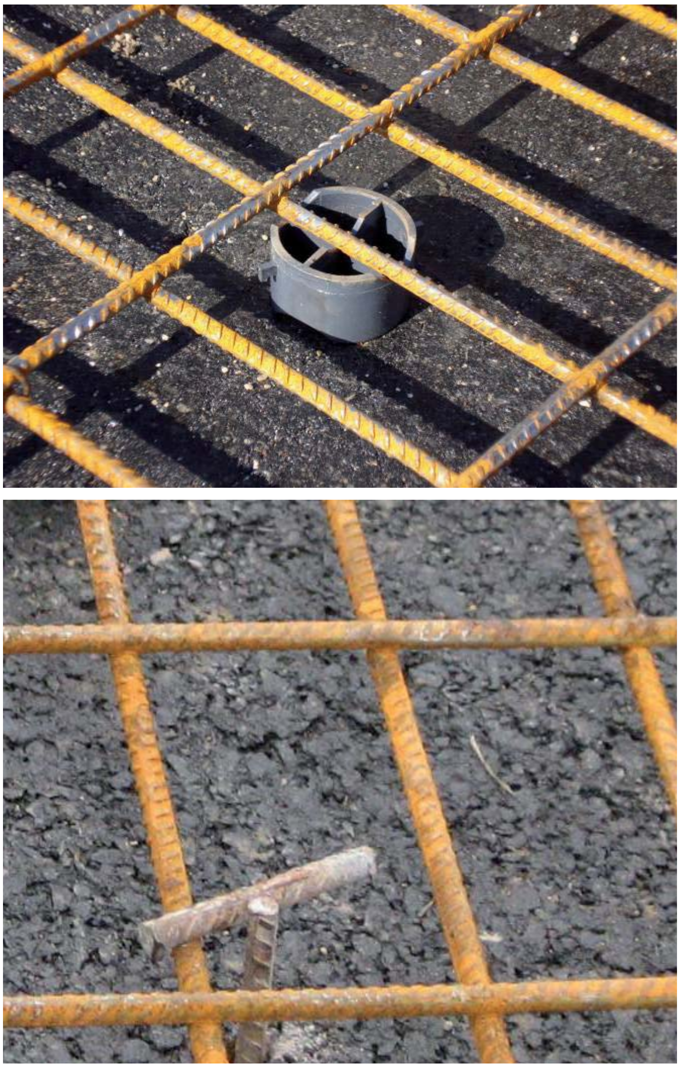

Figure 4: Spacer blocks (left) and steel T-pieces (right) to fix the reinforcement mesh in middle layer

Mixing of Concrete

Pre-mixing and batching of the mix components has already been discussed above. The standard specifications for UTCRCP do not allow mixing the concrete in a ready-mix truck and prescribe that the mixing take place using batch mixers, because ready-mix trucks cannot provide sufficient mixing energy to properly disperse the steel fibres through the mix. It should also be noted that due to the rapid-hardening nature of the concrete mix, there is only a limited time-frame for any transportation of the mix to the point of application.

The mixing of the concrete for the construction of the truck crawling lane at the Huguenot Tunnel on National Route 1 therefore took place in a mobile unit on-site directly at the place of application. This mobile unit consisted of a flat-bed crane truck fitted with a pan mixer (500l capacity), generator and water reservoir. Also, the a number of bulk bags required for one batch of concrete each could be loaded onto the back of the crane truck. Figure 5 (left) illustrates the mobile mixing unit.

The concrete mix components were added sequentially to the pan mixer in the following order: stone, sand, pre-bagged cementitious material, remaining cement, water and admixtures, steel fibre (see Figure 5, right). The concrete was mixed continuously for approximately 5 minutes before the steel fibres were added to the mix in order to ensure that the admixtures have time to react before the steel fibres are added. The water for the mixing was the only mixing component that was measured off during the on site mixing process. The fact that all other components were pre-weighed and pre-batched ensured high control over the mix proportions and eliminated the possibility of erroneously adding incorrect amounts of a certain component to the mix (the entire content of one bulk bag was required for one batch of concrete). During the latter part of the construction of the truck crawling lane the daily production was increased by doubling the mixing capacity of the mobile mixing plant. This was achieved by attaching a trailer with a second pan mixer to the crane truck. A useful feature that was also added to the mobile mixing unit was a shade cover extending over the work area where the concrete was placed (see Figure 5, left).

Figure 5: Mobile mixing plant on the back of a crane truck (left); addition of steel fibres to mix (right)

The cycle time to produce one batch of concrete (approximately 0.33 m3) in the above set-up (one pan mixer) was on average 17 minutes. The total daily production (one pan mixer) was on average around 30 mixes (approximately 10 m3). When using two pan mixers the production was increased by approximately 75% (production did not double when using two pan mixers, because other activities in the production process became critical, most notably the finishing off of the layer).

Placing and Compacting

Placing of the concrete mix took place by discharging the mix down a chute by gravity. The chute was extendable allowing discharge at increasing offsets from the mobile mixing unit. After discharging, the mix was further evenly spread using shovels, as shown in Figure 6. The workability of the mix proved to be good enough to ensure proper and even spreading. Compaction of the concrete took place first by hand using 26 mm hand-held poker vibrators. This was followed by a rotating, triple-screed oscillating roller (see Figure 7).

Figure 6: Discharge of mix down the chute (left) and further spreading of mix by hand (right)

The oscillating roller was imported from the USA for the purpose of the construction of the truck crawling lane UTCRCP. It is however a standard piece of equipment with no need for further modifications. The roller screed is used to spread, tamp and vibrate the concrete, while internal compaction of the concrete is achieved by using the poker vibrators. Special care was taken to ensure that the concrete adjacent to the square tubing side forms was properly compacted. Also, a logical and consistent pattern was followed by the poker vibrators (drawing lines in longitudinal direction working from the sides towards the centre) ensuring that each section of the UTCRCP received equal compaction effort. It proved necessary to have experienced operators on the poker vibrators as it was easy to over compact the concrete, resulting in segregation of the mix.

Figure 7: Triple-screed oscillating roller using square tubing side forms as rails

Finishing of Surface

The surface finish was obtained using hand operated bull floats applied at right angles to the longitudinal. In some cases small hand held floats were required to correct minor imperfections. After the floating the final surface finish was obtained by texturing the concrete using a tine grooving rake. The texturing at the truck crawling lane was applied at an angle of 60°, which improves surface drainage on the downhill section and also reduces the emission of tyre-pavement interaction noise.

The standard specification for UTCRCP allows for a choice between average random tine spacing of either 13 mm or 26 mm on the tine grooving rake. Burger, Ebels and Brink (2010) found that the 13 mm random spacing resulted in too many steel fibres being "combed" up and dislodged, resulting in a very rough surface.

The 26 mm average random spacing was therefore used for the truck crawling lane UTCRCP, which resulted in an acceptable surface texture of at least 1.0 mm (see Figure 8). It is however noted that the timing of the application of the final surface texture is critical (concrete surface needs to have hardened to the right extent before raking the grooves.

Figure 8: Texturing using tine grooving rake (left); final surface texture, 26 mm average spacing (right)

After the texturing a wax-based curing compound was sprayed on the surface. An application rate of 0.8 l/m2 was aimed for. It was found that this application rate was on the high side resulting in run-off of excess curing compound.

To overcome this problem the total application was split into two sprays, applying the second spray after the compound of the first application had dried to a certain extent.

During the initial stages of the construction project, the finished surface was also covered with a plastic membrane, which proved to work counterproductively because in some cases wind pick-up of the plastic sheeting created a "wind tunnel" resulting in an increased draft of the finished surface. In lieu of the plastic sheeting the total application rate of the wax based curing compound was increased. In addition, low mobile canopies made of standard roof sheeting were used to cover the newly constructed concrete for a period of 24 hours.

LABOUR UTILISATION

As mentioned above, the UTCRCP truck crawling lane at the Huguenot Tunnel on National Route 1 was constructed entirely by hand. This means that no self-powered machines, which spread, compact, finish, texture and cure the concrete operating on side-forms were used. Also, no slipform concrete paver was used. Instead, the production process was split into sizeable operations to be carried out by a team of labour operating equipment and tools by hand where required. The total plant and equipment utilisation for the production of the UTCRCP can therefore be considered minimal.

A summary of the plant and equipment utilisation is as shown in Table 4 and a break-down the labour utilisation per activity as shown in Table 5.

Table 4: Plant and equipment usage

Process	Plant and equipment required	No. required
Pre-mixing and batching	small wheel loader crane truck	1 1
Site preparation, formwork and steel fixing	none	-
Mixing of concrete	crane truck with trailer generator 500l pan mixer water truck	1 1 2 1
Placing and compacting	triple screed roller 26mm vibratory poker	1 2 (+ 1 on stand-by)
Finishing of surface	bull float tine grooving rake	1 1

Table 5: Labour usage

Process	Description of labour	No. required
Pre-mixing and batching	unskilled labour trainee technician	12 1
Site preparation, formwork and steel fixing\	unskilled labour ganger supervisor	13 1 0.5
Mixing of concrete	unskilled labour ganger trainee technician supervisor	13 1 1 0.5
Placing and compacting	skilled labour supervisor	10 0.5
Finishing of surface	skilled labour supervisor	4 0.5

An analysis of the labour utilisation in relation to the plant and equipment usage shows that the construction of UTCRCP is relatively labour-intensive. The total labour utilisation is as follows and results in a total labour force of 45 people:

- 25 No. unskilled labour;
- 2 No. gangers;
- 14 No. skilled labour;
- 2 No. trainee technicians;
- 2 No. supervisors.

ECONOMIC CONSIDERATIONS

It should be noted that although the construction of UTCRCP may be considered labour-intensive in terms of the ratio between plant / equipment and labour utilisation, a significant part of the construction costs is the cost of materials. The unit costs per material component and the material cost per cubic metre of concrete for UTCRCP is shown in Table 6.

Table 6: Material input costs per component (2008 prices)

Item	Concrete mix component	Unit	Rate	Proportion per m3 [kg]	Cost per m3 of concrete
1	Cement	t	R 1400.00	480 – 180*	R 420.00
2	Pre-bagged dry cementitious components	t	R4150.00	341	R 1415.15
3	Stone (6.7mm)	t	R 230.00	972	R 223.56
4	Water	kl	R 10.00	175	R 1.75
5	Sand: 1.2 mm to 2.4 mm	kg	R 2.00	178	R 356.00
6	mill feed	kg	R 0.40	506	R 202.40
7	Super-plasticizers: Chryso Premia 100	l	R 25.00	4 l	R 100.00
8	Chryso Optima 100	l	R 30.00	2.4 l	R 72.00
9	Steel Fibre (30 mm hooked fibre)	kg	R 16.50	100	R 1650.00

*** 180 kg of the 480kg of cement is included in the pre-bagged dry cementitious components.**

It follows that the material cost per cubic metre of concrete for UTCRCP is approximately R 4,440/m^3. This translates to a concrete mix cost (excluding steel mesh) of approximately R 222.00/m^2. The material cost of the steel reinforcement mesh adds approximately another R 73.00/m^2, which means that the total material costs of UTCRCP is in the order of R 295.00/m^2 (2008 prices). The plant and labour cost for the construction of UTCRCP is estimated at R 160.00/m^2.

This brings the total construction cost for the UTCRCP to R 455.00/m^2. To allow for any incidentals and additional costs that are not covered by any of the above material cost analysis and plant / labour costs it seems reasonable to add 10% to the costs, which brings the total estimated costs for the construction of UTCRCP (excluding any mark-up and profit) to approximately R 500.00/m^2. These costs are for the construction of the UTCRCP only.

As mentioned previously, the UTCRCP functions as a composite structure of the asphalt interlayer and the concrete UTCRCP. The costs of the 30 mm fine continuously graded asphalt interlayer is estimated at R 80.00/m^2. This brings the total construction cost of the UTCRCP with asphalt interlayer to approximately R 580.00/m^2 (2008 prices).

It is noted that all prices discussed above exclude 14% Value Added Tax (VAT). It is furthermore noted that the above mentioned prices are project and time specific.

Other projects (e.g. different location, size and environment) implemented during different economic climates may result in different prices. The above prices should therefore be regarded as indicative only.

CONCLUSIONS

The construction of the 4.3 km long truck crawling lane between the Huguenot Tunnel and the Huguenot Toll Plaza was the first successfully completed full-scale implementation of UTCRCP as pavement rehabilitation option in the world.

By successfully implementing this new and innovative technique it was demonstrated that it is practically possible to implement UTCRCP on a large and commercial scale.

By and large, the mix design used for the UTCRCP truck crawling lane did not deviate from the specifications that were developed by SANRAL based on the results of various previous research and pilot projects.

The main effort was in ensuring that the local mix constituents were of such quality that the concrete mix properties comply with the strict requirements of the specifications. In this regard it is noted that strict control over the grading as well as the moisture content of the sand component is required.

It was found that the use of processed sands as used in the glass and foundry industry meet these demands. It was also found the shape factors of the aggregate (6.7 mm stone) such as Flakiness Index and Average Least Dimension have a significant effect on the strength of the concrete mix, whereby the use of more cubicle aggregate results in higher strength.

One of the key success factors of the construction of the UTCRCP truck crawling lane was the amount of off-site preparation in terms of pre-mixing some of the dry cementitious components and pre-batching of the mix constituents. This offered good control over the mixing process and significantly reduced the possibility for incorrectly measuring off mix proportions during the actual concrete mixing process. The concrete mixing took place in a mobile on-site mixing unit resulting in optimum workability of the mix during placing and compacting.

Labour is extensively used for the construction of UTCRCP. A large part of the labour component required may be fairly low skilled and the requirements for training and education required for the tasks to be performed are not onerous.

Average production rates of up to 360 m2 per day were achieved with a total labour force of 45 people and two 500 litre mixers. The capital outlay required for plant and equipment is limited and a breakdown of any such items required is provided in the paper.

A considerable component of the costs of UTCRCP is in materials. Approximately 60% of the cost of UTCRCP (excluding the asphalt interlayer) is in materials. The total costs of the combination of 50 mm UTCRCP on top of a 30 mm asphalt interlayer is estimated at R 580/m2 excluding any profit margin and VAT (2008 prices).

DISCLAIMER

This paper reflects the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The content does not reflect the official views or policies of the South African National Roads Agency Ltd (SANRAL).

REFERENCES

Braam, C.R., Buitelaar, P. and Buitelaar, N., *Reinforced High Performance Concrete Overlay System for Steel Bridges*, Proceedings of 5th International CROW Workshop on Fundamental Modelling of the Design and Performance of Concrete Pavements, Istanbul, Turkey, 2004.

Burger, A.F., Ebels, L.J. and Brink, A.C., *Experience with the Construction of an Ultra-thin Continuously Reinforced Concrete Pavement*, Proceedings of 11th

International Symposium on Concrete Roads, Sevilla, Spain, 2010
COLTO (Commission of Land Transport Officials), *Standard Specifications for Road and Bridge Works for State Road Authorities*, Pretoria: South African Institution of Civil Engineering, 1998.
CSRA (Committee for State Road Authorities), *Standard Test Methods of Testing Road Construction Materials*, Technical Methods for Highways (TMH) 1, 2nd edition, Pretoria: Council for Scientific and Industrial Research, 1986.
Kannemeyer, L., Perrie, B., Strauss, P. and Du Plessis, L., *Ultra-thin Continuously Reinforced Concrete Pavement Research in South Africa*, pp 97-124 of the Proceedings of International Conference on Concrete Roads, Midrand, South Africa, 2007.
Kannemeyer, L., Perrie, B., Strauss, P. and Du Plessis, L., *Ultra Thin CRCP Development in South Africa*, Proceedings of 9th International Conference on Concrete Pavements, San Francisco, USA, 2008.
Strauss, P. J., Slavik, M., Kannemeyer, L. and Perrie, B.D., *Updating CnCPave: Inclusion of Ultra-thin Continuously Reinforced Concrete Pavement (UTCRCP) in the Mechanistic Empirical and Risk Based Concrete Pavement Design Method,* Proceedings of International Conference on Concrete Roads, Midrand, South Africa, 2007.