

IMPROVING RUNWAY SKID RESISTANCE AT KING SHAKA INTERNATIONAL AIRPORT THROUGH ULTRA-HIGH PRESSURE WATER-CUTTING

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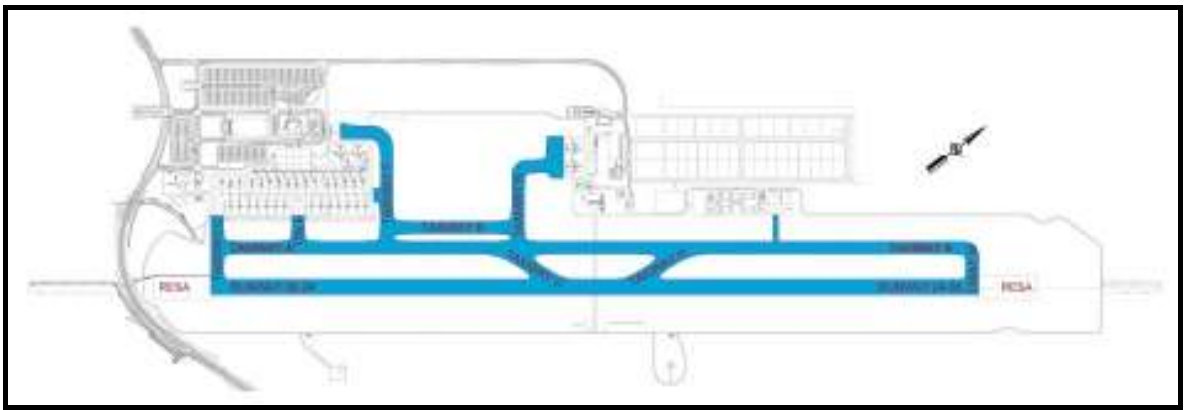
ABSTRACT

The authors of the paper were involved in the design and the construction of the new King Shaka International Airport in Kwa-Zulu Natal, South Africa as part of the consulting engineering team. The runway and taxiways of the airport were constructed with stone mastic asphalt (SMA) wearing course with a 13.2 mm maximum aggregate size. This paper presents the findings of the research conducted in establishing a suitable treatment for the improvement of the skid resistance of the runway to compliance with the ICAO Annex 14 recommendations. Ultra-high pressure (UHP) water-cutting was chosen as the preferred treatment, and trial sections were conducted to establish the application rates. The paper discusses the findings of all tests conducted during the trial sections as well as the final skid resistance and macro-texture results obtained on the runway after implementation of the UHP water-cutting.

1. INTRODUCTION

The aircraft movement area of the King Shaka International Airport (KSIA) consists of the following elements, as shown in the layout below:

- Runway 06/24;
- Parallel Taxiways A and B (both to the left of Runway 06/24);
- Transverse Taxiways C, E, F, N, P, M;
- Rapid Exit Taxiways G and H;
- Aprons A, B, C, D and E (Heliport).



All the taxiways have a width of 60 m except for Taxiway P which is 15 m wide and only serves the heliport. In general, Runway 06-24 can be classified as a Category 4F instrumented runway in accordance with ICAO Annex 14, with the predominant approach being from the north at Threshold 24 (60/40 split).

The runway and taxiway pavements were constructed with a 40 mm thick Stone Mastic Asphalt (SMA) wearing course on two 40 mm thick binder course layers of medium continuously graded hot-mix asphalt. The 3-layer surfacing structure was preferred to ensure that exceptional riding quality is achieved.

Stone mastic asphalt was preferred to continuously graded hot-mix asphalt as wearing course for the pavement elements of the KSIA airside due to its proven higher rutting resistance, but also due to it showing better skid resistance after time due to less rubber built-up.

The mix design of the SMA wearing course was conducted in compliance with the *Interim Guidelines for the Design of Hot-mix Asphalt in South Africa (IGHMA) (2001)*, taking cognizance of the project specific requirements. There are different approaches internationally towards SMA gradations, especially in respect of the nominal maximum aggregate size (NMAS) and the material passing through the 2.36 mm sieve (the distinction between the coarse and fine fractions). Excessively coarse gradations used in the past for SMA mixes in South Africa yielded poor durability due to high permeability and low density, and subsequent premature failures. Durability is highly dependent upon the permeability of the mix, and thus dependent upon the NMAS and layer thickness.

In view of the surfacing thickness of 40 mm a maximum aggregate size of 13.2 mm was chosen for the SMA mix and the grading thereof was established within the tolerances of the standard specifications. The chosen grading resulted in a densely packed stone-on-stone skeleton which yielded excellent

resistance to permanent deformation and excellent durability. These characteristics were further enhanced through the use of a high quality polymer modified binder.

The chosen grading of the SMA, however, also yielded macro-texture and skid resistance values which were less than the recommended values pertained in the ICAO Annex 14, Volume I (July 2004) Recommendations for Aerodrome Design and Operations. The Airports Company of South Africa (ACSA) insisted that the recommended values must be implemented, resulting in the Contractor opting to implement hydro-cutting as an improvement measure on recommendation of the Consulting Engineers.

Ultra-high pressure (UHP) water-cutting was preferred as skid-resistance treatment by the Consulting Engineers due to its high speed of implementation compared to grooving and its elimination of the need for additional non-renewable resources associated with resurfacing.

2. SKID RESISTANCE OF AIRPORT PAVEMENTS

The skid resistance of an airport pavement surfacing is mainly a function of the micro-texture of the aggregates in the case of low travelling speeds and the macro-texture of the surfacing in the case of high travelling speeds. Figure 1 below illustrates the difference between micro-texture and macro-texture.

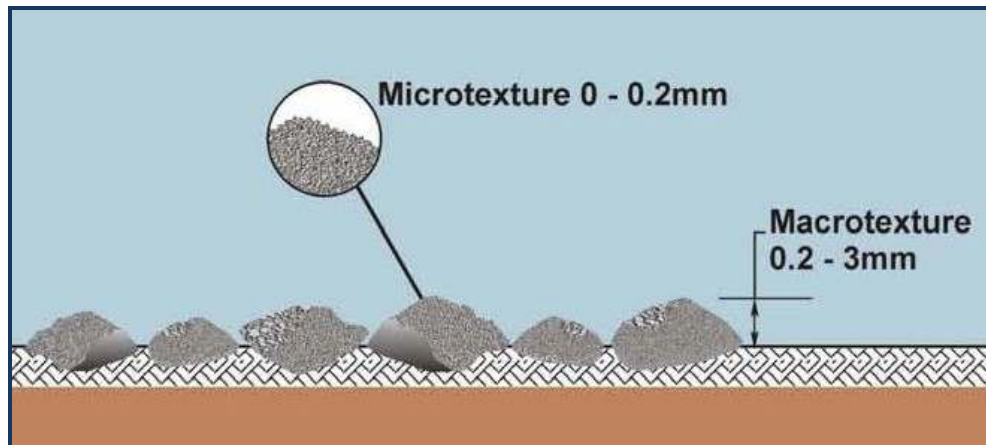


FIGURE 1 : MICRO-TEXTURE VS MACRO-TEXTURE

Micro-texture is normally measured by means of the British pendulum skid tester (BS 812) (see Figure 2) in terms of the polished stone value (PSV). The macro-texture of a surfacing has traditionally been measured by means of the sand patch test in South Africa. However, the Australasian developed sand circle (ASC) texture test (see Figure 3) has become popular in South Africa during recent years due to its short testing period and simplicity. In addition to these tests it has become the norm in South Africa to determine the macro-texture of a surfacing in terms of the Mean Profile Depth (MPD) by means of laser profilometer equipment such as the Dynatest Road Surface Profiler 5051, Mk11.

It is believed that micro-texture fulfils a lesser role than macro-texture in the provision of skid resistance for airport pavements, due to the heavy wheel loads and high travelling speeds of the aircraft on the runway. The ICAO Annex 14 recommends a minimum macro-texture depth of 1.0 mm for airport runways.



FIGURE 2 : PENDULUM SKID TESTER



FIGURE 3 : SAND PATCH TEST AND ASC TEST

The ICAO Annex 14, Volume I recommends several apparatus for the measurement of skid resistance, inter alia the SCRIM and Grip Tester. Recommendations are made (Attachment A-7, July 2004) in terms of the design objective level (DOL) for a new surfacing, the maintenance planning level (MPL) and the minimum friction level (MFL) for all equipment at various speeds, all being significantly less than the travelling speed of the aircraft at landing and taking-off. The recommendations in respect of the Grip Tester are summarised in Table 1.

TABLE 1 : ICAO ANNEX 14 SKID RESISTANCE ACCEPTANCE LIMITS

GRIP TESTER SPEED	MINIMUM FRICTION LEVEL (GN)	MAINTENANCE PLANNING LEVEL (GN)	DESIGN OBJECTIVE (GN)
65 km/h	0.43	0.53	0.74
95 km/h	0.24	0.36	0.64

In addition to the surfacing characteristics of an airport pavement, its geometry also impacts upon the wet weather performance of the pavement. It is believed that this aspect of the design is more significant in providing a facility which will ensure safe wet weather operations than the skid resistance of the runway wearing course, especially for airports which experience high intensity rain storms such as OR Tambo International and King Shaka International.

3. UHP WATERCUTTING HISTORY AND APPLICATION

The Ultra-high pressure (UHP) water-cutting technology has been widely used in both Australia and New Zealand for over the past decade and has proven to be a cost effective treatment for the restoration of texture and skid resistance on road and airport pavements. The UHP water-cutting machine was designed and fabricated in New Zealand by Fulton Hogan Limited. UHP water-cutting is used to extend the service life of pavement surfacings which did not comply with the specifications for texture and / or skid resistance during its design life. UHP water-cutting has also been found an efficient method for the removal of rubber deposits on the Touch Down Zones (TDZ) of runways by the Australian and New Zealand airport authorities.

The UHP water-cutting process was developed to cut the uppermost surface using fine needles of water jetted at speeds of up to 1800 km/h, as illustrated in Figure 4 below. The fineness of the water jets results in the energy being dissipated on contact with the surface, allowing the bituminous mastic to be removed without stone loss and without increasing the permeability of the surfacing. Research (Waters and Pidwerbesky, 2008, p. 7) conducted on behalf of Land Transport New Zealand showed that water-cutting improves both the micro-texture of polished aggregates and the macro-texture of a surfacing, but it also exposes the micro-texture of the unpolished aggregates, resulting in improved skid resistance at both low and high travelling speeds as illustrated in Figure 5 below.

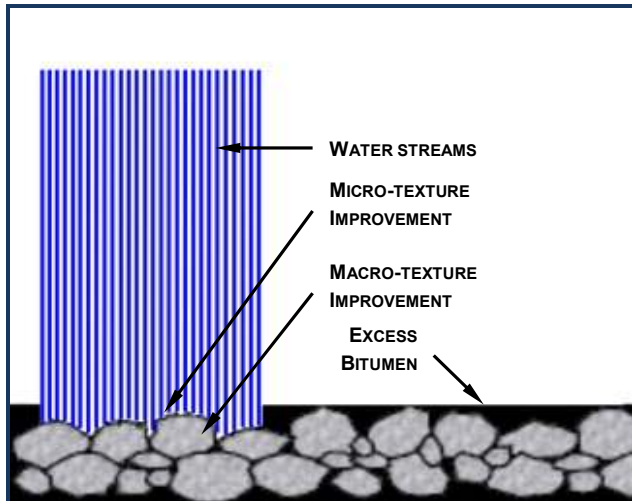


FIGURE 4 : SCHEMATIC ILLUSTRATION OF WATER-CUTTING



FIGURE 5 : EFFECT OF WATER-CUTTING ON TEXTURE



FIGURE 6 : BACKVIEW OF UHP WATER-CUTTER



FIGURE 7 : VIEW OF UMBILICAL DECKBLASTER

The UHP water-cutting equipment includes variable pressure settings in order to allow the operator to remove less or more material as may be required. The removal of the bituminous mastic is achieved by means of the vacuum system and umbilical deckblaster (cutting head) attached to the ultra-high pressure water source. Figures 6 and 7 above shows the latest water-cutting equipment developed by Fulton Hogan Limited and imported to South Africa by Shisalanga Asphalt in Kwa-Zulu Natal.

4. IMPLEMENTATION OF WATER-CUTTING AT KSIA

Paving of the 40 mm thick stone mastic asphalt (13.2 mm maximum aggregate size) wearing course commenced during August 2009 on Runway 06-24 from the 06-end. After the completion of the first 900 m of the centre strip (8 m wide), the skid resistance of the surfacing was tested by means of the Grip Tester Mk II. The equipment is owned by Specialised Road Technologies (Pty) Ltd and is frequently used by the ACSA to monitor the skid resistance of the pavements of its airports. It was decided to use the Grip Tester Mk II to undertake skid resistance measurements at KSIA to ensure uniformity in the method of assessing and reporting of runway and taxiway friction conditions. The results of the Grip Tester Mk II skid resistance testing are reported in terms of the Grip Number (GN).

The Grip Tester results were found to be acceptable with the recorded GN in excess of the ICAO Annex 14 recommended values for the design objective level (DOL). The SMA wearing course for the runway was completed towards the end of October 2009 and testing was again implemented for the purpose of approval and acceptance by ACSA on 03 November 2009. However, this round of testing yielded significantly lower GN values, even less than the minimum friction level (MFL). It was concluded that the macro-texture of the SMA surfacing was filled with silty sand, which caused the poor test results. A short section of the runway was cleaned by means of pressure water jetting and brooming, and retested. This experiment indicated that the skid resistance improved over the cleaned area and the contractor was instructed to clean the complete runway prior to retesting the skid resistance by means of the Grip Tester.



FIGURE 8: VIEW OF GRIP TESTER



FIGURE 9: VIEW OF DYNATEST ROAD SURFACE PROFILER

On 24 November 2009 the engineering team re-evaluated the skid resistance and macro-texture of the cleaned runway, using the Grip Tester and the Dynatest Road Surface Profiler 5051, Mk11 respectively (see Figures 8 and 9 above). Sand patch tests were also conducted on the SMA surface. The contractor was also asked to prepare an area on the parallel taxiway where the binder film of the SMA wearing course was removed by means of sand blasting to simulate the expected surfacing condition after traffic. The skid resistance testing yielded results above the recommended MFL-value, but mostly lower than the maintenance planning level (MPL). The sand patch tests conducted on the cleaned runway yielded results in macro-texture varying between 0.6 mm and 0.8 mm.

Figures 10 and 11 below summarise respectively the Grip Tester and Road Surface Profiler results for the various runs conducted along the runway. The 100 m section in the middle of the runway was not cleaned and still contained dirt as a result of a temporary haul road crossing.

In contrast with these test results the tests conducted on the strip which was cleaned by means of light sand blasting yielded excellent results with the average GN = 0.81 at 65 km/h, indicating that removal of the binder film from the surface of the wearing course could address the problem. Figure 12 below shows the effect of the sandblasting on the surface texture. However, the sandblasting did not address the ICAO Annex 14 recommendation in respect of a minimum macro-texture of 1.0 mm, as the macro-texture measurements recorded with the Road Surface Profiler varied between 0.7 mm and 0.8 mm Mean Profile Depth (MPD).

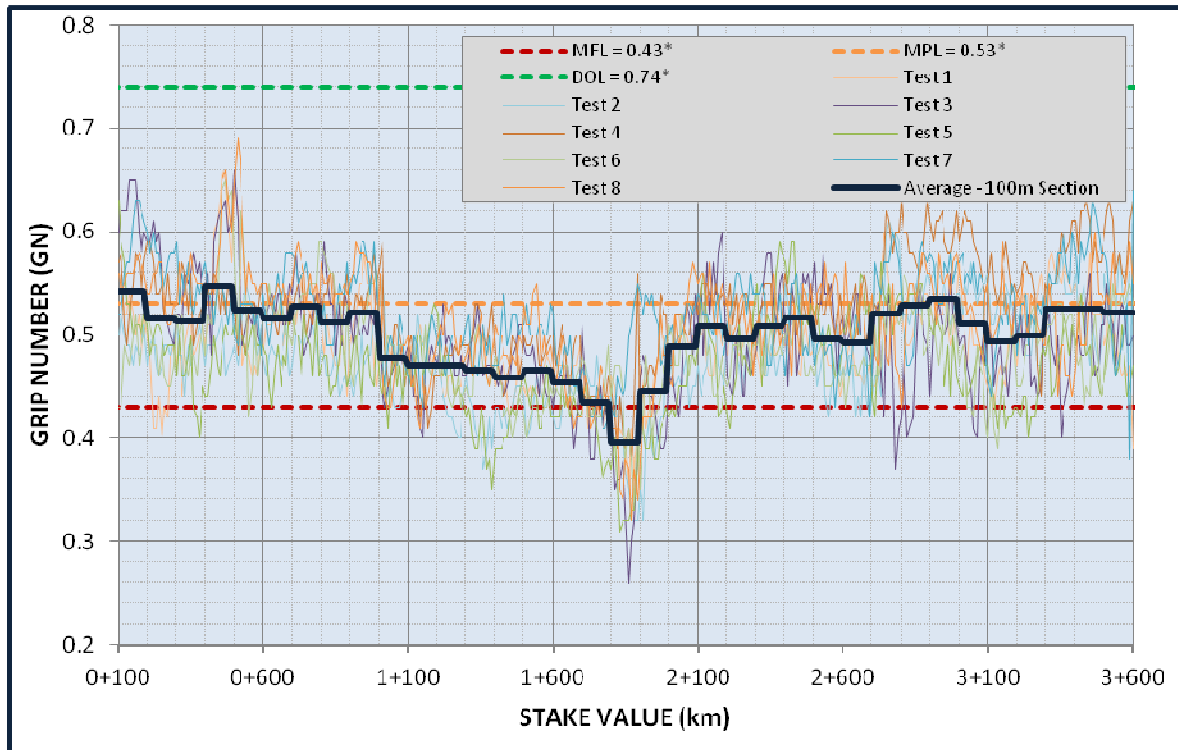


FIGURE 10 : SKID RESISTANCE TEST RESULTS OF CLEANED RUNWAY SURFACE

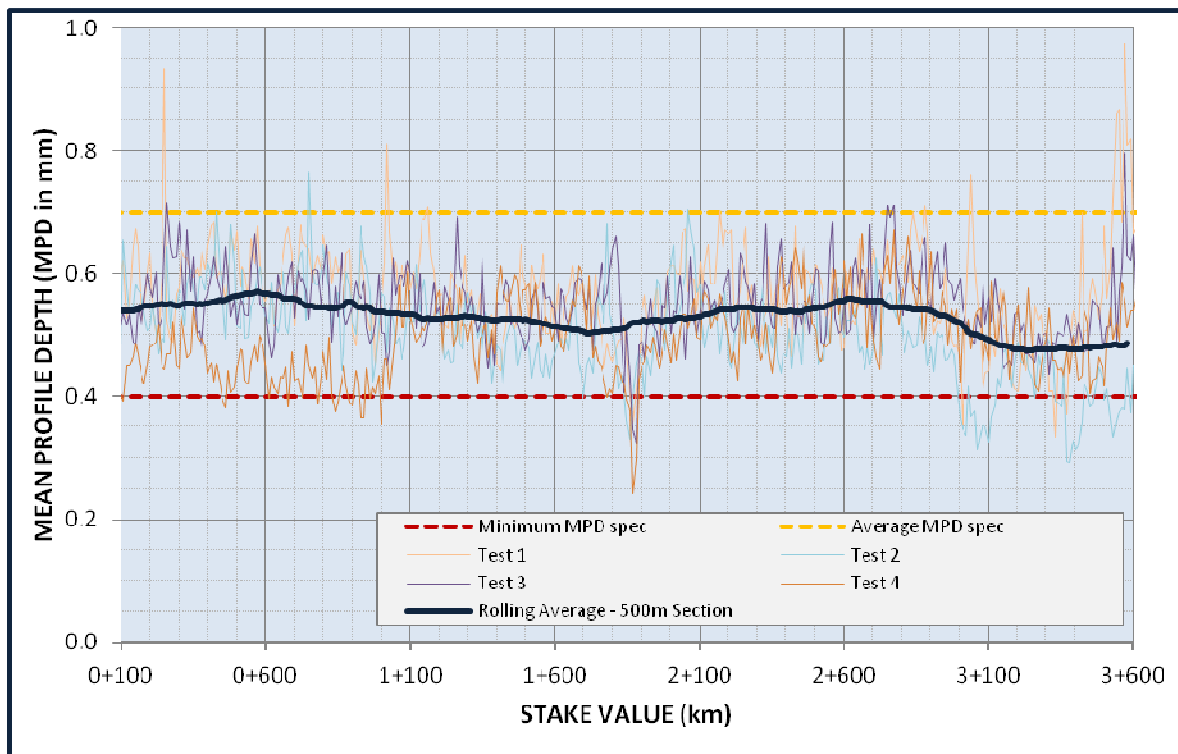


FIGURE 11 : DYNATEST ROAD SURFACE PROFILER MEAN PROFILE DEPTH TEST RESULTS



FIGURE 12 : EFFECT OF LIGHT SANDBLASTING ON THE SURFACE TEXTURE OF THE SMA WEARING COURSE

In view of these findings, the engineering team proposed to the contractor to implement water-cutting to remove the binder film and any dirt from the surface of the wearing course. On 01 March 2010 the

contractor mobilized the water-cutting team of Shisalanga Asphalt to conduct a trial section on the parallel taxiway.

4.1 Findings of the UHP Water-cutting Trial Section

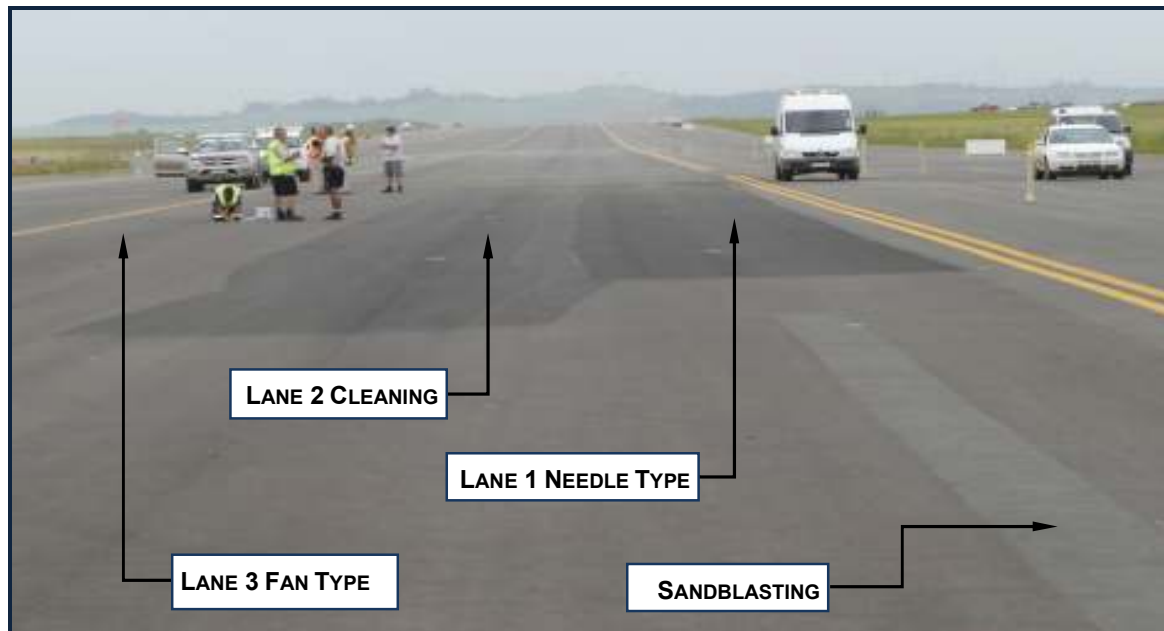


FIGURE 13 : VIEW OF WATERCUTTING TRIAL SECTION, SHOWING LANE DISTRIBUTION

The UHP water-cutting trial section was conducted 03 March 2010 to determine the speed and pressure applications to implement a macro-texture of 1.0 mm without damaging the surface integrity. Three lanes of 3.5 m width were prepared at different speeds and pressures, with the trial section illustrated in Figure 13 above. The sandblasted strip is also shown in Figure 13 above.

The test configuration of the three lanes consisted of the following:

- Lane 1 was treated with a mild water-cutting application at 400 bar pressure with a needle type water jet (see Figure 14) at a travelling speed of 3.5 m/min;
- Lane 2 was treated using only washing and vacuuming the surface to clean it of dust and sand by water jetting at 200 bar without cutting at a travelling speed of 4.5 m/min; and
- Lane 3 was treated using a mild water-cutting application at both 500 bar and 600 bar with a fan / dovetail type jet (see Figure 14) at a travelling speed of 3.5 m/min.

Skid resistance and macro-texture testing was conducted prior to and after water-cutting. These test results are compared in Table 2 below for the different water-cutting applications. Figure 15 shows the comparable test results obtained from the sand patch test and the ASC test. This comparison provided confidence in implementing the ASC test for process control purposes, with the two tests yielding similar results for all the areas.



FIGURE 14 : COMPARISON OF WATER JET TYPES



FIGURE 15 : COMPARISON OF MACRO-TEXTURE TEST

TABLE 2 : SUMMARY OF RESULTS OF TEXTURE AND SKID RESISTANCE MEASUREMENTS CONDUCTED ON TRIAL SECTIONS

LANE NO	NO OF TESTS	TREATMENT TYP	NOZZLE TYPE	APPLIED PRESSURE (BAR)	TRAVEL SPEED (M/MIN)	ASC BEFORE TREATMENT	ASC AFTER TREATMENT	SAND PATCH AFTER TREATMENT	GRIP TESTER NO AFTER TREATMENT	
									65 KM/H	95 KM/H
1	6	Mild water-cutting	Needle	450	3.5	0.52	1.00	1.02	0.79	0.64
2	6	Wash and vacuum only	None	200	4.5	0.50	0.82	0.65	-	-
3	3	Mild water-cutting	Dovetail	500	4.5	0.50	0.90	0.87	0.74	0.64
3	3	Mild water-cutting	Dovetail	600	4.5	0.50	1.00	0.95	0.77	0.66

The water jetting cleaning treatment on Lane 2 yielded a muddy sludge as illustrated by Figure 16, with Figure 17 showing the water-cutter in action during the treatment of Lane 1. The high-pressure cleaning and vacuuming treatment on Lane 2 improved the ASC measured macro-texture of the SMA wearing course from 0.5 mm to 0.7 mm on average.



FIGURE 16 : MUDDY SLUDGE EXTRACTED ON LANE 2



FIGURE 17 : START OF OF LANE1 WATER-CUTTING

The mild water-cutting treatment on Lane 1 with the 400 bar water pressure and needle jets resulted in fairly aggravated improvement in macro texture with ASC measured texture depths varying between 0.9 mm and 1.2 mm. Concerns were raised that the aggressive treatment could result in the early dislodgement of surface aggregates, and it was decided to use the fan jet or dovetail jet as it is also called

instead of the needle jet. This led to the test on Lane 3 in which the necessary pressure was determined to achieve the ICAO Annex 14 recommended macro-texture of 1.0 mm. The recommended value was achieved at a water pressure of 600 bar with the dovetail jet. Unlike the surface of Lane 1, which was watercut with the needle jet, the bituminous binder was not entirely stripped from the aggregates as is illustrated by Figure 18 below.

The water cutting in Lane 1 extended over the joint between the SMA wearing course of the taxiway travelway and the medium continuously graded HMA wearing course of taxiway shoulder, as illustrated by Figure 19 below. The ASC comparative testing revealed that even for the continuously graded asphalt a significant improvement in the macro-texture is achieved by means of the water-cutting, with the texture depth increasing from 0.5 mm to 0.7 mm.



FIGURE 18 : VIEW OF WATER-CUT MACRO-TEXTURE



FIGURE 19 : TEXTURE IMPROVEMENT OF AC MEDIUM

After all testing was concluded, the area was flooded with water from a water browser to observe the impact of the water-cutting upon the surface drainage. This experiment showed that the run-off flow increased significantly, confirming that the improved macro-texture will ensure better wet-weather performance of the runway. The photo pertained in Figure 20 below was taken moments after the water was sprayed on the test section, with the water-cut areas of Lanes 1 and 3 appearing much drier than the washed Lane 2 and the shoulder area without water-cutting.



FIGURE 20 : WATER RUN-OFF EXPERIMENT

4.2 Effect of UHP Water-cutting on Durability

Concerns were raised by the representatives of the ACSA, the contractor and the consulting engineering team that the UHP water-cutting could affect the durability of the asphalt, based upon the assumption that too much mastic and fines were removed from the surface matrix of the SMA wearing course. It was agreed between the parties that additional comparative testing needs to be conducted to determine whether the water-cut section is worse off than the uncut section. For this purpose cores were taken from the surfacing of Lane 3 (Test Positions #1 to #3) and Lane 1 (Test Positions #4 to #6) and subjected to the Cantabro Abrasion test.

The Cantabro Abrasion test is normally used for open-graded hot-mix asphalt, such as open-graded porous asphalt (OGPA) to determine its resistance to ravelling under traffic loading as a result of the oxidation of the binder film. No guidelines exist for the acceptance limits of the Cantabro Loss as far as could be established through literature reviews. However, it is expected that the SMA mix used for the KSIA wearing courses will be less prone to ravelling than open-graded HMA due to the denser grading, higher binder content, lack of interconnected voids and the use of polymer-modified binder. The risk of premature failure due to ravelling would therefore be negligible if the results of the Cantabro Abrasion tests conducted on the SMA mix comply with the accepted limits for open-graded asphalt.

The SMA of the trial section already experienced a complete summer at the time of the tests, and it is suspected that a significant amount of ageing / oxidation already took place, but was not established. Herrington *et al* (2005) established the durability acceptance limits of aged and unoxidised OGPA as 30% loss and 15% loss respectively, using the Cantabro Abrasion test. The SABITA Manual 17 (1995) specifies an acceptance limit of 35 % loss for unoxidised porous asphalt.

Table 3 below summarises the findings of the comparative testing, with Reference "A" indicating the cores taken from the untreated sections adjacent to the trial section and Reference "{L3-1; L3-2; L3-3}" and "{L1-1; L1-2; L1-3}" demarcating the cores taken from the UHP water-cut treated Lane 3 (dovetail nozzle) and Lane 1 (needle nozzle) respectively. The increase in the % loss listed was determined in respect of the average value of the % loss on the cores taken from the SMA without the water-cutting, equal to

6.08%. The listed findings are presented graphically in Figure 21 below. The results indicate that the durability of the SMA surfacing was affected more severely by the needle nozzle water-cutting than the dovetail nozzle water-cutting as the increase in weight loss of these samples were significantly more than the average % loss of the untreated samples. It should also be noted that in general the lower core density resulted in higher % loss during the Cantabro Abrasion test.

TABLE 3 : SUMMARY OF CANTABRO ABRASION TEST RESULTS

TEST POSITION	SMA WITHOUT UHP WATERCUTTING			TRIAL SECTION AFTER UHP WATERCUTTING			INCREASE IN % LOSS
	CORE NO	CORE DENSITY (KG/M ³)	% LOSS	CORE NO	CORE DENSITY (KG/M ³)	% LOSS	
1	A1	2302	8.2	L3-1	2293	9.6	58%
2	A2	2376	6.6	L3-2	2347	10.9	79%
3	A3	2367	5.6	L3-3	2353	9.3	53%
4	A4	2389	5.6	L1-1	2320	19.3	217%
5	A5	2340	6.4	L1-2	2315	24.9	309%
6	A6	2365	4.1	L1-3	2331	10.2	68%

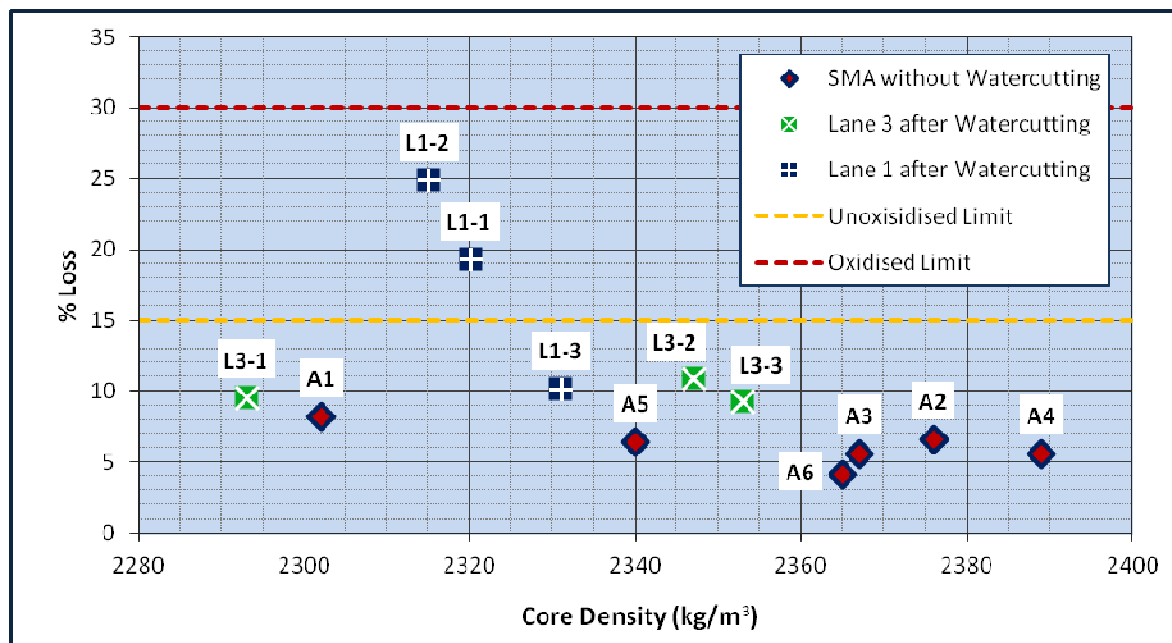


FIGURE 21 : CANTABRO LOSS VS CORE DENSITY

4.3 Conclusions and Recommendations from the Watercutting Trial Section

It was concluded from the results of UHP water-cutting experiment that the treatment of the SMA wearing course with the water-cutting will ensure that a uniform macro-texture is obtained which is compliant with all the recommendations pertained in the ICAO Annex 14 Design Guidelines for Aerodromes. In view of the favourable findings of the experiment, the consulting engineering team proposed to the contractor to implement the UHP water-cutting, since it also negated the need for grooving in the touchdown zones. The UHP water-cutting did not result in additional cost, as the cost allowed for the grooving was significantly more, and it in fact resulted in a cost saving.

The Cantabro Abrasion testing conducted also confirmed that the application of the UHP water-cutting using the dovetail nozzles at the proposed pressure and speed will not result in premature failure due to insufficient durability, with the % Cantabro loss after water-cutting still well below the acceptance limits proposed for open-graded asphalt.

5. IMPLEMENTATION OF UHP WATERCUTTING ON THE RUNWAY

The UHP water-cutting was implemented as follows on recommendation of the consulting engineering team:

1. The Shisalanga Asphalt Ultra-high Pressure Water-cutter was used to remove the excess binder film from the Stone Mastic Asphalt (SMA) surfacing, using the dovetail jets at a pressure of 600 bar and travelling at a speed of 4.5 metre per minute.
2. The UHP water-cutting was applied in three strips of 3.0 m width on each side of the centreline paint markings over the full length of the runway.
3. The works were monitored visually on a continuous basis for the complete duration thereof and also by means of the Australasian Sand Circle (ASC) macro-texture test, to ensure that the necessary macro-texture is achieved throughout during the UHP water-cutting and that no excessive treatment takes place. The Ilembe Engineering JV mobilised a qualified pavement engineering technician to conduct this monitoring.
4. The final testing and reporting consisted of the following:
 - a. Reporting of macro-texture measurements conducted at random offsets and 20 m stake values during the UHP water-cutting treatment; and
 - b. Skid resistance testing by means of the SRT Grip Tester at offsets of 3.0 m and 5.0 m on both sides of the centreline in both directions.

5.1 Macro-texture Test Results

The monitoring was done using the Australian Sand Patch method and the results of the measurements are summarised in Figure 22 below. An average macro-texture of 0.998 mm was achieved, with a minimum value of 0.972 mm. The UHP water-cutting therefore resulted in the macro-texture of the runway being compliant with the ICAO Annex 14 recommendation. The figure also indicates the length of water-cutting applied for each 3.0 m wide strip per day, as the average texture depth for each work section is plotted.

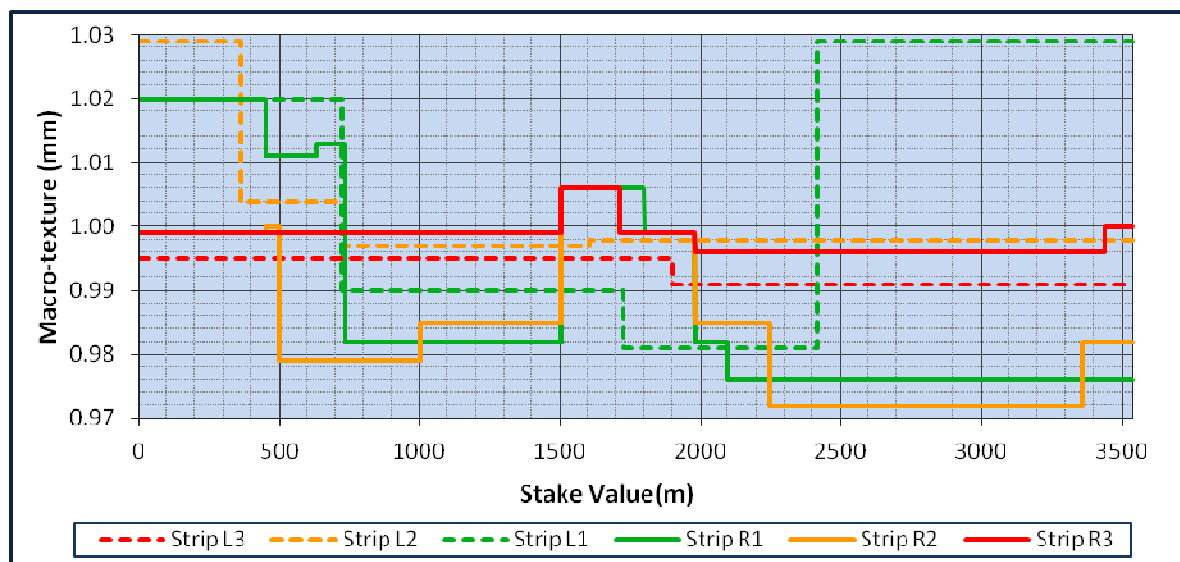


FIGURE 22 : SUMMARY OF MACRO-TEXTURE MEASUREMENTS AFTER UHP WATER-CUTTING

5.2 Skid Resistance Test Results

It is stated in the ICAO Annex 14 that the State should establish values for the Minimum Friction Level (MFL) and the Maintenance Planning Level (MPL). It is further stated that the average of all measurements for the complete runway or a “significant portion” thereof should be compared with the established values of MFL and MPL to determine whether any actions are required to improve the skid resistance. A “significant portion” is defined in Section 10.2.4 of the ICAO Annex 14 as 100 m.

The skid resistance of the runway was tested by means of the Grip Tester at offsets of 3.0 m and 5.0 m on both sides of the centreline in both directions, resulting in a total no of eight tests. The results of these tests are summarized in Figure 23 below.

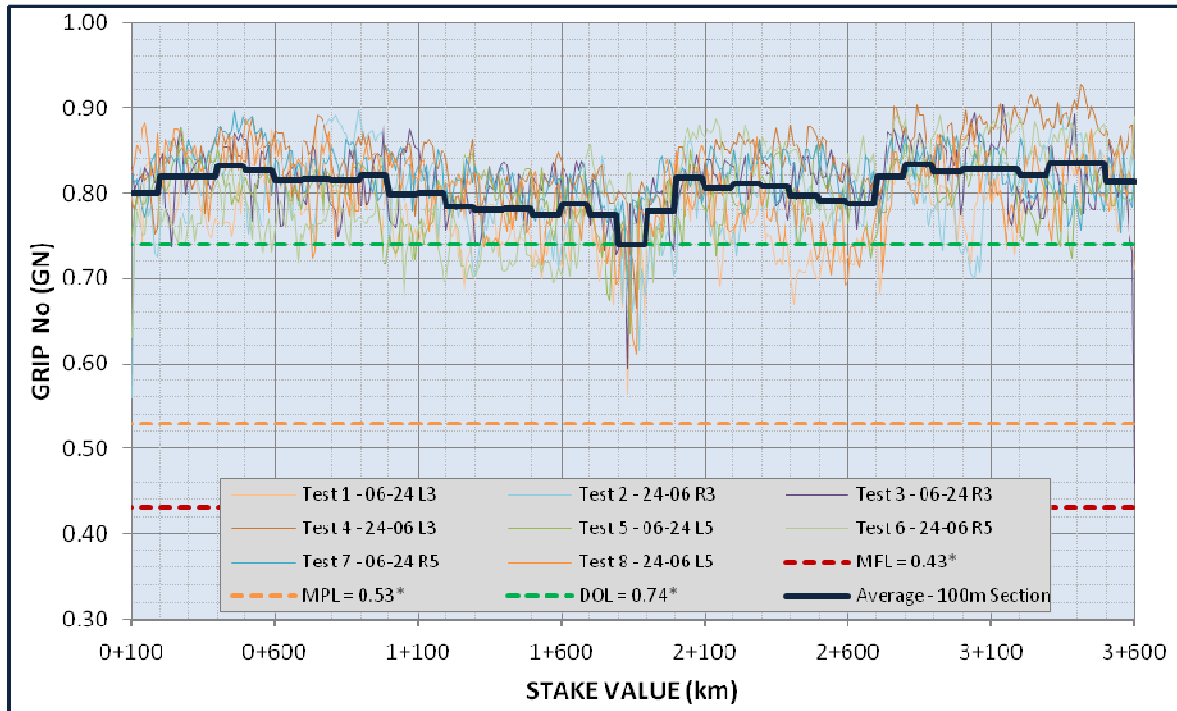


FIGURE 23 : SUMMARY OF GRIP TESTER RESULTS AFTER UHP WATER-CUTTING OF COMPLETE RUNWAY

It was concluded that the UHP Water-cutter improved the skid resistance, as measured with the Grip Tester from a level below Maintenance Planning Level (as illustrated by Figure 10) to a level above the Design Objective Level of 0.74 at a speed of 65 km/h, resulting in full compliance with the ICAO Annex 14 recommendations for new runways.

6. CONCLUSION

Ultra-high pressure (UHP) water-cutting was chosen as the preferred treatment for the improvement of the micro-texture and macro-texture, and subsequent skid resistance, of the King Shaka International Airport runway surfacing. The alternative treatments, including ultra-thin friction course and grooving, would have cost at least an order of magnitude more than the UHP water-cutting, would definitely not have been completed within the 32 days it took to apply the water-cutting, and also would not have addressed all the requirements as effectively as the water-cutting did.

The studies conducted in Australasia and referred to in this paper, concluded that UHP water-cutting can be repeated on a surfacing more than once to extend the life thereof. Rubber built-up on the touch-down zones of runways is a continuous problem which the Airports Company of South Africa (ACSA) need to address, and it is believed that UHP water-cutting is the ideal treatment to address this problem on all its airports.

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KEYWORDS

Ultra-high (UHP) water-cutting; Runway skid resistance; Surfacing macro-texture