Laboratory Evaluation of the Deformation Resistance of Asphalt Surfaces for Airfields under Static Loads

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ABSTRACT: This paper presents the laboratory work carried out to evaluate the deformation resistance of asphalt surfacings for airfields under static loading conditions. An indentation test, based on the French test for airfield pavements known as the “puncturing test”, was used to characterise the resistance of a mixture to deformation as a result of high static loads. The materials investigated were two AC 10 surface course mixtures produced with two different polymer modified binders, and a 14 mm Marshall Asphalt surface course mixture. The AC 10 mixtures were designed following the French design method for 0/10 mm Béton Bitumineux Aéronautique continuously graded mixtures whereas the 14 mm Marshall Asphalt surface course mixtures was designed as per the UK Defence Estate specifications for military airfields. It was found that the indentation test developed in this study is a suitable tool to characterise the resistance of a mixture to indentation from static loads. Furthermore, indentation values for the AC 10 mixtures were markedly lower than those for the Marshall Asphalt indicating better resistance to deformation under static loads. As regards the AC 10 mixtures, the mixture produced with the harder PMB was more resistant to indentation than the one produced with the softer PMB.

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KEY WORDS: Indentation, asphalt, airfields, static loading.

1 INTRODUCTION

Airfield pavements must meet certain specialist performance requirements to provide safe aircraft operations. For instance, the runway should have an even surface regularity and, good skid resistance and surface water drainage for good and safe braking. For taxiways, parking areas and service aprons, on the other hand, one of the main requirements is adequate resistance to deformation as result of high tyre loads from slow moving or standing aircrafts.

High static aircraft loads can lead to surface defects consisting of indentations at locations where the tyre is in contact with the asphalt surface. This can then cause local deformation and often results in water ponding. The indentation on the surface is sometimes the results of a single even for example during a period of hot weather and is not necessarily associated with the repeated application of the load.

Most of the laboratory tests to evaluate the deformation resistance of asphalt mixtures are, however, dynamic or cyclic tests where the loads are repeatedly applied to the specimen. These types of tests include for instance wheel tracking, repeated creep, triaxial tests and others (Partl et al., 2012). Furthermore, the wheel loads and pressures or stresses applied during these tests are akin to vehicle and traffic loading but are not representative of the contact pressures applied by the tyre of a large aircraft when the aircraft is not moving.

In this work, an indentation test has been developed to investigate the resistance of various asphalt airfield surfacing mixtures to deformation as a result of static loads. The test closely follows the French “puncturing test” for airfield pavements (NF, 1988). This test is typically carried out during the mix design work of surfacing materials for airfield pavements for parking areas and link sections where static airplane loads are relevant.

The materials investigated in this study were two AC 10 surface course mixtures produced with two different polymer modified binders (PMB), and a 14 mm Marshall Asphalt (MA) surface course mixture. The AC 10 mixtures were designed following the French design method for 0/10mm Béton Bitumineux Aéronautique continuously graded (AC 10 - BBA C) mixtures for airfields whereas the 14 mm Marshall Asphalt (MA) surface course mixtures was designed following the UK Defence Estate specifications for military airfields.

It was found that the indentation test developed in this study is a promising tool to characterise the resistance of a mixture to indentation from static loads. Furthermore, indentation values for the AC 10 mixtures were found to be markedly lower than those for the Marshall Asphalt indicating better resistance to deformation due static loads. As regards the AC 10 mixtures, the mixture produced with the harder PMB was more resistant to indentation than the one produced with the softer PMB.

2 INDENTATION TEST

2.1 Test set-up

In an indentation test a static load is applied on top of an asphalt specimen using an indentor pin with a circular base. The load is applied for a period of time at a constant temperature and the penetration of the indentor into the specimen (indentation) is measured. There are currently two standards indentation test for mastic asphalt and rolled asphalt i.e. EN 12697-20 and EN 12697-21. There is not, however, a standard indentation test for other types of mixtures.

In this work a servo-pneumatic machine was used to apply the load by means of an actuator. The actuator had incorporated a transducer that measured its vertical position and therefore the penetration of the indentor into the specimen. The indentor was a half steel ball of 25.2 mm diameter and a surface area of 500 mm^2. The flat side of the ball was positioned on the centre of the asphalt specimen. Furthermore, two transducers measured the vertical deformation of the surface of the specimen at 30 mm from its centre. Figure 1 shows the indentation test set-up.

The parameters measured during the indentation test included the applied load, the temperature, the indentation and the deformation of the surface of the specimen measured with two transducers. A typical test result showing the indentation on the specimen and the deformation of the specimen surface with time is shown in Figure 2.

The asphalt specimens used were cylindrical cores of 220 mm nominal diameter. The thicknesses of the cores were 50 mm approximately. The advantage of using these relatively large specimens was to provide some level of confinement around the loading area. Furthermore, jubilee clips were used to increase the confinement level. Two clips were used to restrain the bottom 30 mm of the specimen leaving the top 20 mm un-restrained (see Figure 1). It should be noted that in the French puncturing test the specimen is sealed in a plaster cylindrical mould in order to keep 20 mm untightened height.

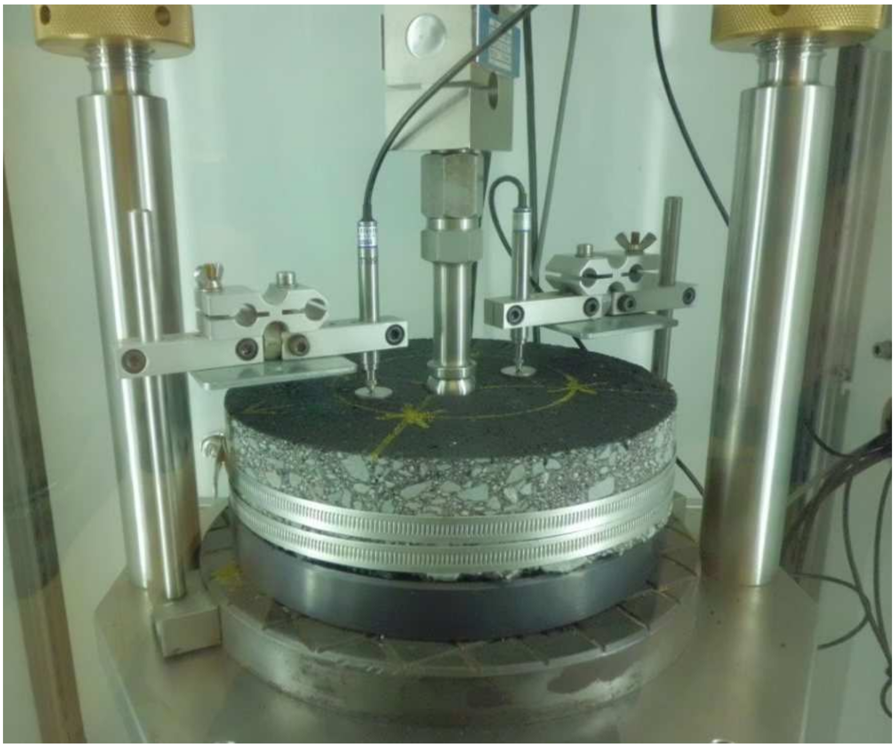

Figure1: Indentation test set-up

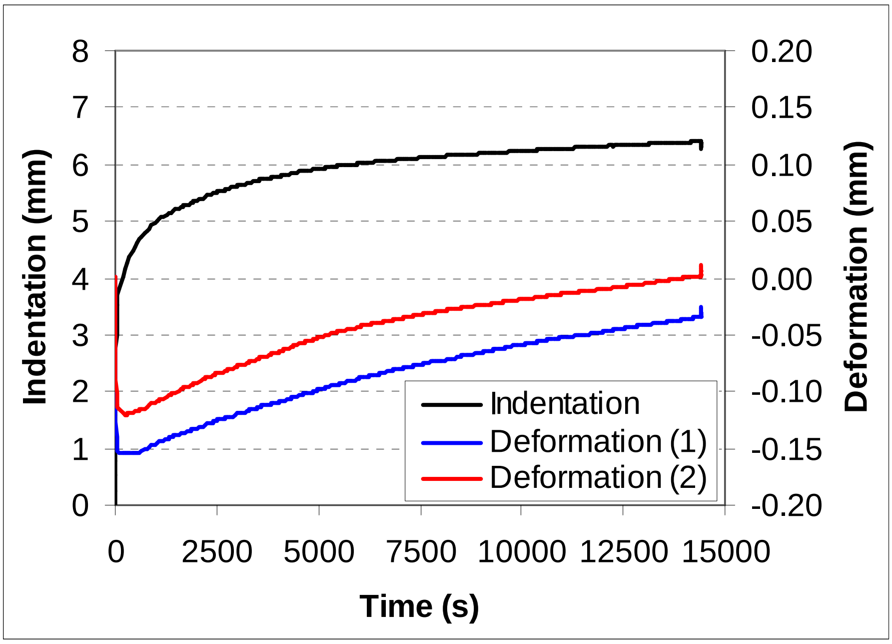

Figure 2: Indentation and vertical deformation (AC 10 PMB100, 2 kN and 50 ^{0}C)

2.2 Test Conditions

Different load levels i.e. 1, 2 and 4 kN were used in the study. This gave contact pressures of 2000, 4000 and 8000 kN/m^2. The applied load was then maintained for 4 hours. The tests were carried out at two temperatures 50 and 60 ^{0}C. The procedure consisted of applying first a contact load of 0.02 kN. The load was then increased to the target load in 10 seconds at the corresponding loading rate. Once the target load was reached it was then kept constant for 4 hours. After 4 hours the specimen was unloaded at the same rate and time as the loading sequence. It should be noted that the test conditions used in study included those reported in the French puncturing test, i.e. test temperature of 50 ^{0}C, 1 kN (100 daN) load , surface are of the indentor of 5 cm^2 (500 mm^2) and 4 hours duration.

Moreover, in the indentation test the contact pressures applied on the surface of the asphalt specimen are equivalent to those imparted by a large aircraft. For instance, for a Boeing 777-300 (Boeing, 2011) the maximum weight at the centre of gravity is 141 tonnes approximately (313900 lbs). Given that the aircraft has six wheels per main gear, the weight per tyre is about 23.5 tonnes. The tyre contact area for this aircraft is an ellipse of 0.157 m^2 (243.3 in^2). Thus, the pressure applied on the surface by a single tyre is 1467 kN/m^2 approximately. In the indentation test, the pressure applied on the surface of the asphalt specimen when the applied load is 1 kN is 2000 kN/m^2. Table 1 shows a comparison between the contact pressure applied by the tyre of a large aircraft and the pressure applied during the indentation test.

Table 1: Comparison between aircraft and indentation test contact pressures

Properties	Boeing 777 - 300	Indentation test
Maximum taxi weight (tonnes)	297	−
Maximum weight at centre of gravity (tonnes)	141	−
No. of tyres per main gear	6	−
Weight per tyre (tonnes)	23.5	−
Load per tyre (kN)	230.3	1
Contact area (m^2)	0.157	0.0005
Contact shape	Ellipse	Circle
Major axis (m)	0.56	0.0252
Minor axis (m)	0.35	0.0252
Contact pressure (kN/m^2)	1467	2000

3 MATERIALS

The materials investigated in this study were two AC 10 surface course mixtures and a 14 mm Marshall Asphalt (MA) surface course mixture. The AC 10 mixtures were designed following the French design method for 0/10mm Béton Bitumineux Aéronautique continuously graded (AC 10 - BBA C) mixtures for airfields (Delorme et al. 2007). Porphyric andesite aggregates and limestone filler and two polymer modified binders, a medium grade 40/100-45 (PMB50) and a soft grade 75/130-50 (PMB100), were used to produce two AC 10 surface course mixtures.

A 14 mm Marshall Asphalt (MA) surface course mixtures, on the other hand, was designed following the UK Defence Estate specifications for military airfields (MoD, 2005). The MA mixture was manufactured using granite aggregates, limestone filler and hydrated lime. Furthermore, the binder used was a 70/100 pen grade bitumen. Also, it should be noted that the MA mixture was mixed at plant whereas the AC 10 mixtures were produced in the laboratory. Table 2 shows the mixture design procedure and requirements for the two types of airfield asphalt surfaces AC 10 - BBA C and 14 mm Marshall Asphalt. Also, particle size distribution of the AC 10 and MA mixtures used in the study together with typical and specified limits for AC 10 - BBA C and 14 mm Marshall Asphalt respectively, are presented in Table 3.

Table 2: Mixture design requirements

Material	Design method	Property	Limits
14 mm Marshall Asphalt Surface course	Marshall Asphalt mixture design	Optimum Binder content (%)	5 - 7
		Flow (mm)	< 4.00
		Air voids (%)	3 - 4
		Voids filled with binder (%)	76 -82
AC 10 - BBA C Surface course	French bituminous mixture design	Minimum binder content (%)	5.4
		Water sensitivity (ITSR)	> 80 %
		Air voids @ 60 gyrations	3 - 7
		Max. Proportional rut depth Wheel tracking large device 60 ^{0}C, 10000 cycles	7.5 (Class 3)

Table 3: Grading and binder content

Sieve size	% Passing			
mm	AC 10	Limits AC 10 - BBA C	MA	Limits 14 mm MA SC
20	−	−	100	100
14	100	100	100	86 - 100
10	98	90 - 100	89	78 - 90
6.3	78	65 - 80	77	66 - 79
4	56	−	−	−
2	40	35 - 45	53	43 -57
1	28	−	41	31 - 46
0.5	−	−	30	21 - 36
0.25	16	10 - 25	−	−
0.125	−	−	9	7 - 14
0.063	10.3	6 - 9	5.4	2 - 6
Binder content (%)	5.7	5.4 (min)	5.5	5 - 7

Laboratory prepared AC 10 and MA mixtures were compacted to 305 x 305 x 50 mm^2 slabs using a laboratory roller compactor following EN 12697-33 as a guide. Six slabs were produced for each mixture. The target air void content for the compacted slabs was 4 %. One specimen of 220 mm diameter was then cored from each slab. Bulk densities and air voids of each of the cores were then determined in accordance with EN 12697-6 (Proc. A – dry) and EN 12697-8 respectively. Furthermore, the maximum density of the mixtures was first determined in accordance with EN 12697-5. Density and air voids values of individual specimens are presented in Table 4.

Table 4: Density and air voids of core specimens

Material	Specimen ID	Max. Density kg/m^3	Density (A) kg/m^3	Air voids %
AC 10 PMB100	1	2519	2426	3.7
	2		2420	3.9
	3		2419	4.0
	4		2425	3.7
	5		2419	4.0
	6		2424	3.8
	Mean	2519	2422	3.9
AC 10 PMB50	1	2519	2414	4.2
	2		2427	3.6
	3		2437	3.3
	4		2431	3.5
	5		2435	3.3
	6		2414	4.2
	Mean	2519	2426	3.7
Marshall Asphalt	1	2488	–	–
	2		2357	5.3
	3		2365	4.9
	4		2367	4.9
	5		2367	4.9
	6		2380	4.3
	Mean	2488	2367	4.9

4 RESULTS AND DISCUSSIONS

4.1 Effect of Applied Load and Temperature

Figures 3 and 4 show the indentation of the two AC 10 mixtures with loading time at various load levels. It can be seen that as the applied load level increased the indentation increased. Also, it can be observed that initially the indentation increased very rapidly and then at a much slower rate. Furthermore, this rate was also dependent on the applied load. At the lowest load level i.e. 1 kN, the indentation remained practically constant during the whole duration of the test. As the applied load increased, both the initial indentation and the indentation rate increased. At the highest load i.e. 4 kN, all the specimens did fail before the completion of the test. Failure was considered when the indentation reached 12 mm or when the indentation rate accelerated rapidly.

Moreover, comparison between the two AC 10 mixtures showed first that at 1 kN load level the indentation values for the mixtures with the PMB100 and PMB50 were very similar. At higher load levels (2 and 4 kN), however, the mixture with the PMB50 showed lower indentation than that with PMB100.

Similarly, Figure 5 shows the indentation for Marshall Asphalt specimens. It can be seen first that as the load increased the indentation increased. Furthermore, all the specimens failed before the termination of the test and the higher the applied load the quicker the specimen failed. It should be also noted that indentation values for the Marshall specimens were markedly higher than those for the AC 10 mixtures. Figure 6 shows a MA specimen after the test was completed. It can be seen that the half steel ball had practically fully penetrated the material after less than two hours at 1 kN load (2000 kN/m^2 contact pressure).

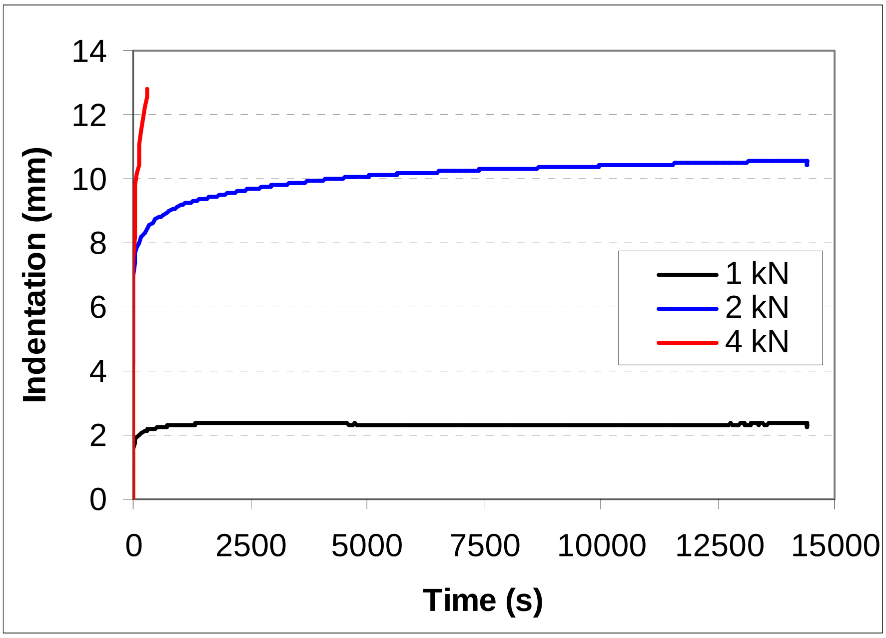

Figure 3: Evolution of the indentation for AC 10 PMB100

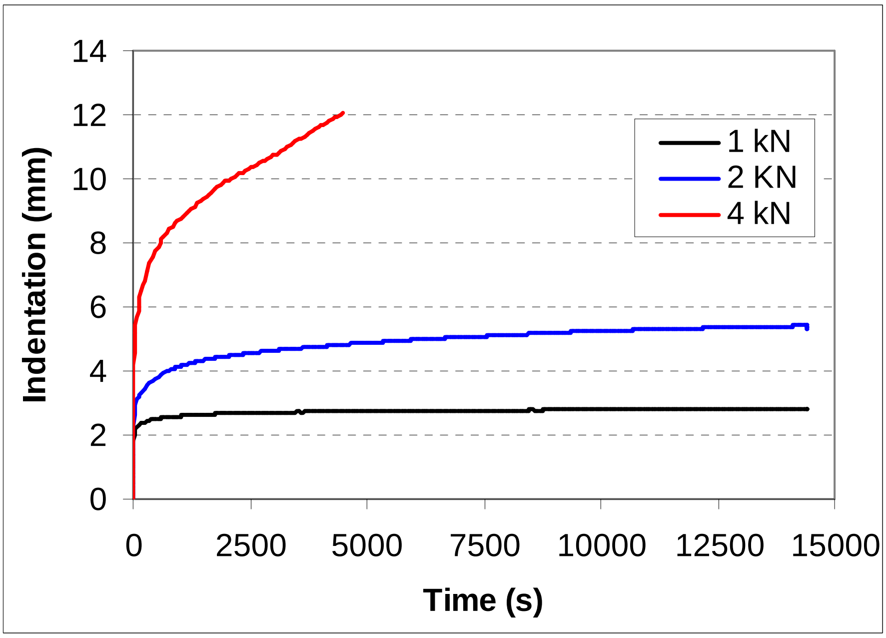

Figure 4: Evolution of the indentation for AC 10 PMB50

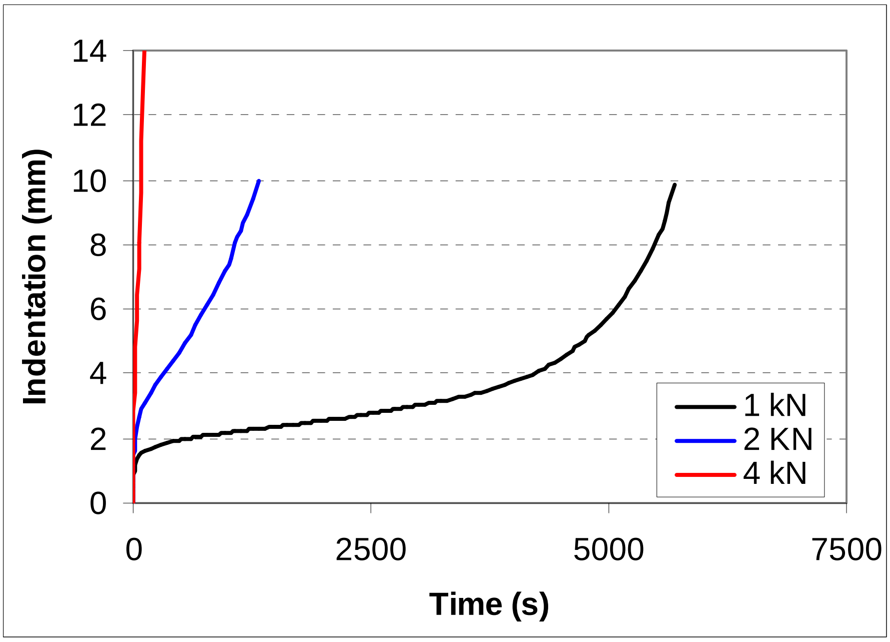

Figure 5: Evolution of the indentation for MA

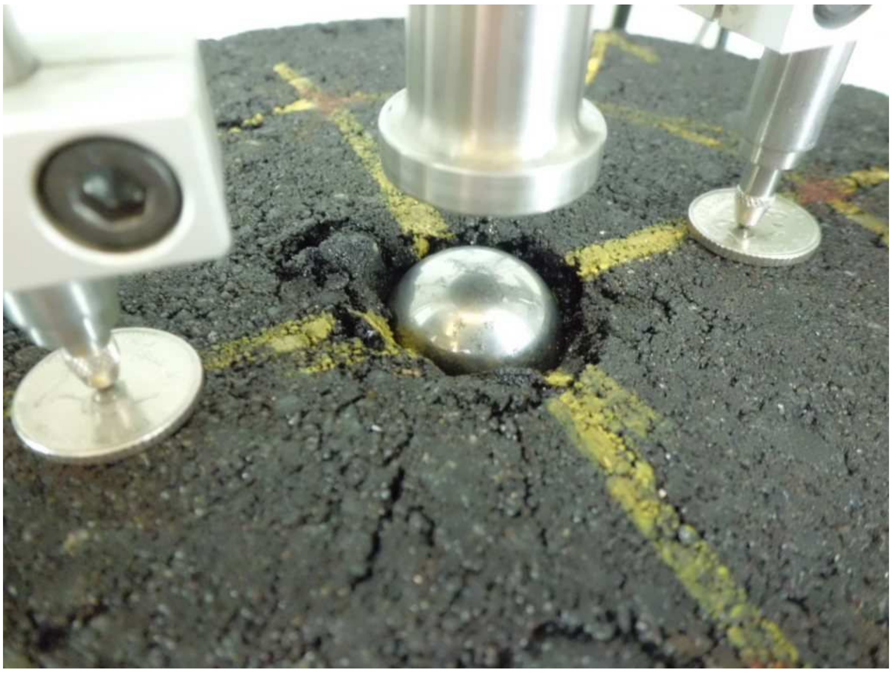

Figure 6: MA specimen after testing at 1 kN load (2000 kN/m^2 pressure)

The effect of temperature on indentation is illustrated in Figure 7. It can be seen that for the AC 10 PMB100, as the temperature increased the indentation also increased. The differences between the indentation values were, however, relatively small i.e. 0.65 mm approximately when the temperature rise from 50 to 60 ^{0}C. Similar behaviour will be expected for the other materials although this will have to be determined.

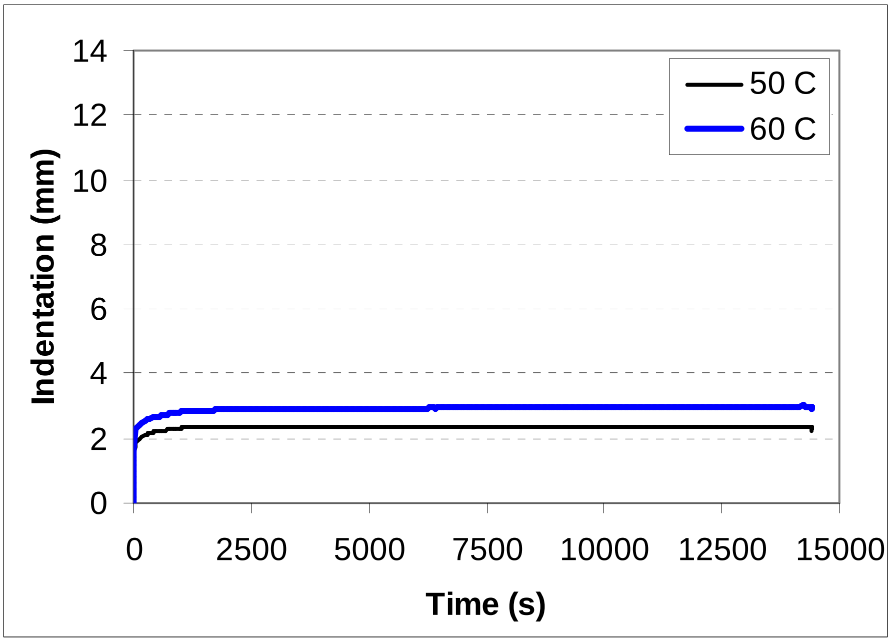

Figure 7: Effect of temperature on indentation (AC 10 PMB100)

4.2 Standard Test Conditions

The test conditions in the French puncturing test for airfield pavements are as follows: temperature 50 ^{0}C, load 1 kN (100 daN), surface area 500 mm^2 (5 cm^2) and 4 hours duration. Furthermore, the specimen is sealed in a plaster mould to keep 2 cm untightened height. Also, the first minute of the test is not taken into account. The material is considered compliant if the indentation is less than 2 mm.

Table 5 shows the indentation test results under standard test conditions based on the French standard. Values in Table 5 include the indentation value determined by substracting the indentation after 1 minute from the indentation after the completion of the test (4 h), as in the French standard. It can be seen that for the standard load i.e. 1 kN, the indentation values for the AC 10 PMB mixtures were below 2 mm and therefore complied with the French standard. The MA, on the other hand, did not comply as the specimen failed before the end of the test. Furthermore, data also showed that when the load was increased from 1 to 2 kN, the indentation values increased to more than 2 mm.

Table 5: Indentation test results at 1 kN (standard load) and 2 kN

Material	Load kN	Indentation @ 1 min mm	Indentation @ 4 h mm	Difference mm	Complies Y /N
AC 10 PMB100	1	1.86	2.35	0.49	Y
	2	3.51	6.40	2.89	N
AC 10 PMB50	1	2.17	2.83	0.66	Y
	2	2.92	5.42	2.50	N
Marshall Asphalt	1	1.48	Failed at 5700 s		N
	2	2.66	Failed at 1320 s		N

5 CONCLUSIONS

Based on the laboratory work the following conclusions can be drawn:

- The indentation test used in this study is a suitable test method to evaluate the resistance to deformation of asphalt mixtures subjected to static loads.
- The test set-up and test conditions used in this work closely follow the French puncturing test. This test is widely used in the mix design process for airfield pavements for surface course materials for parking areas and link sections where static airplane loads need to be considered.
- Contact pressures applied during the indentation test are equivalent to those applied by a tyre of a large aircraft when it is not moving (static).
- Indentation tests showed that as the applied load level increased the indentation increased. Also, the indentation increased very rapidly during the first stages of the test and then it increased steadily at a much slower rate.
- Comparison between AC 10 PMB mixtures showed that in general the indentation values for the mixture with the PMB50 were lower than that with PMB100.
- Indentation values for Marshall Asphalt specimens were markedly higher than those for AC 10 PMB mixtures.
- For laboratory prepared AC 10 PMB100, the indentation increased slightly when the temperature increased from 50 to 60 ^{0}C.
- For standard test conditions, the indentation values for the AC 10 PMB mixtures were below 2 mm and therefore complied with the French standard. The MA, however, did not comply as the specimen failed before the end of the test.
- When the load was increased from 1 to 2 kN, the indentation values for AC 10 PMB mixtures with PMB 100 and PMB50 increased above 2 mm.

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