PAVEMENT MATERIAL THAT IMPROVES RUTTING RESISTANCE ON HEAVY LOADED AREAS

J. SUNDAHL
RAMBOLL, Department of Aviation and Airport, Copenhagen, Denmark
jsu@ramboll.dk

J. ELERT MUNK
RAMBOLL, Department of Roads, Copenhagen, Denmark
jem@ramboll.dk

S. BUNCH
DENSIT A/S, Department of Product Management Aalborg, Denmark
sbu@densit.dk

ABSTRACT

Heavy loads that are present on airfields aprons, on storage areas at industry facilities and on road sections such as bus lanes and bus terminals need pavement materials that are rutting resistant and have a high stiffness modulus, even at low loading frequencies. The traditional selection of materials in these areas has been rigid pavement structures such as cement concrete. However, more flexible materials that can obtain stand deformations without cracking and without joints, both leading to lower maintenance costs, has been asked for. This has resulted in the development of a semi-flexible material for heavy-duty areas.

The semi-flexible pavement material described in this paper consists of an open asphalt structure (5/8, 8/11 mm or 11/16 mm aggregates) where a high strength micro silica mortar is penetrated into the air voids (25 - 30 %) of the asphalt mixture. The results are based on the special type of semi-flexible material called Densiphalt®. The semi-flexible pavement combines the micro silica mortar's strength and the asphalt material's flexibility. The special designed micro silica mortar from Densit A/S has the ability to penetrate entirely into the open asphalt structure, thus ensuring a homogeneous pavement material.

The design stiffness modulus of the semi-flexible pavement has been determined to 8,000 MPa at 25 °C and loading frequency of 33 Hz, 2-3 times higher than for asphalt. The service life of the pavement materials is 15 to 20 years. The material can be constructed in different colours through additives added to the mortar. The finished surface of the material has different appearance depending on the use and requirements to e.g. the friction.

In resent years, the construction of Densiphalt® has been further improved by introducing steel reinforcement at the bottom of the layer. Semi-flexible pavement materials are normally constructed in thicknesses between 40 and 100 mm depending on the load applied on the areas. The steel reinforcement has shown to further improve the rutting resistance and thus enables the use on areas with traditional asphalt layers that need partial repairs. Furthermore, the short curing time of the pavement (between 24 and 48 hours, depending on the air temperature) makes the materials an excellent choice in areas where the time of repair shall be as short as possible.

Semi-flexible pavements have, with excellent results been used for approximately 10-15 years around the world on aprons in airports, storage areas in ports and industrial facilities plus at bus terminals.

KEY WORDS

PAVEMENT / MATERIALS / RUTTING / STIFFNESS / FATIGUE.

1 INTRODUCTION

Heavy static loads that are present on airfield apron, on storage areas at industrial facilities and on road sections such as bus lanes and bus terminals need pavement materials that can sustain the heavy loads. The pavement materials should be very rutting resistant due to the static loads. The traditional selection of materials has been rigid pavements such as cement concrete.

In the recent years, the development of semi-flexible pavement materials has shown that these materials result in better performance, lower construction cost and lower maintenance cost. The semi-flexible pavement materials described in this paper are defined as a composite material of an open graded asphalt material where the air voids are filled with a micro silica cement mortar. In addition, introduction of steel reinforcement (traditionally 6 mm ribbed steel bars) of semi-flexible materials has been introduced to increase the rutting resistance.

Semi-flexible pavement materials have been used in Denmark and worldwide for more than 15 years. This paper describes the properties and experience gained from the use of semi-flexible pavement materials on areas with heavy loads.

2 MATERIAL PROPERTIES

Semi-flexible pavement materials consist of an open graded asphalt pavement where the air voids are filled with a micro silica mortar. The material has, therefore, the flexibility of traditional asphalt materials and the strength of cement concrete. The strength is, however, not as high as for cement concrete. An example of a semi-flexible pavement core is shown in figure 1 where the bright areas are the micro silica mortar.

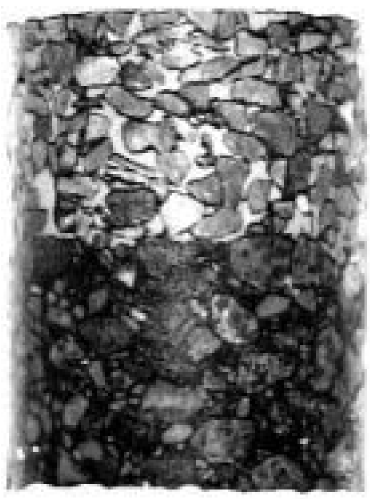

Figure 1 Core of semi-flexible pavement material with bituminous binder course.

2.1 Open graded asphalt

The open graded asphalt material used in semi-flexible pavement material is similar to drainage asphalt. The compacted asphalt material has Marshall air voids of approximately 25 %. An example of an asphalt material is shown in figure 2. The nominal maximum aggregate size is 11.2 mm in this example.

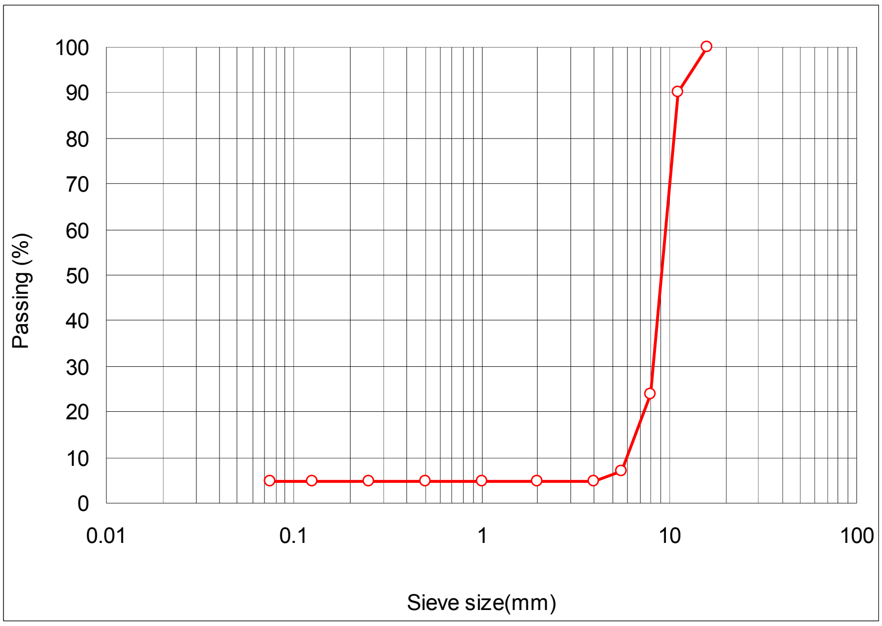

Figure 2 Example of sieve analysis of asphalt material used in semi-flexible pavement material.

The asphalt material is normally delivered with nominal aggregate maximum size 8 mm, 11.2 mm or 16 mm. The aggregates shall be cubical and have a Los Angeles Abrasion value less than 25 %.

The bitumen used in the asphalt materiel has penetration values between 40/60, 70/100 or 160/220. The choice of type of bitumen is depending on the climate and the actual load on the areas where the semi-flexible pavement is used. On areas with very high load the harder bitumen 40/60 is chosen whereas on areas with limited bus traffic, the bitumen 160/220 is chosen due to its better ageing properties. The bitumen is most often straight-run bitumen. Polymer modified bitumen has not been considered as an alternative due to satisfactory results from using straight-run bitumen.

Normally, the binder content of the open graded asphalt is about 4 % depending on the aggregate used. Cellulose fibres are added to the mixture to avoid separation of the asphalt mixture during transport. The content of these fibres are normally 0.2-0.3 % of the total used aggregates. Traditional adhesion improvement agents such as hydrated limestone are also added. The amount of hydrated limestone is approximately 1-1.5 % of the aggregates.

2.2 Micro silica mortar

The micro silica mortar used in semi-flexible pavement materials is high strength cement-based mortar. The micro silica has a compressive strength after 28 days of hardening at 20 ºC of approximately 100 MPa. The micro silica mortar achieves its properties through an improved cement binder with an extremely dense microstructure. The mortar contains approximately 100 times smaller particles than normal cement.

The main reason for using micro silica mortar instead of traditional cement mortar is the high strength of the micro silica mortar. This results in a high density where the mortar becomes impermeable and chemical resistant. Experience from the use of traditional cement has shown that the mortar does not provide sufficient strength to the pavement material. The use of micro silica mortar with the high compressive strength, however, shows that satisfactory properties of the composite material can be obtained.

2.3 Semi-flexible pavement material

The composite product called semi-flexible pavement consisting of the open graded asphalt with air voids filled with micro silica mortar can be described by the following requirements:

- Powder Index shall be between 110 and 130 %.
- The compressive strength after 7 days according to BS 1881 shall be 7-10 MPa.
- The freeze-thaw resistance according to SS 137244 shall be “Very good”.

The powder index is calculated by:

$$Powder\ Index = 100 \times \frac{used\ powder\ amount - wasted\ powder\ amount}{theoretical\ powder\ amount}$$

The above-mentioned requirements result in semi-flexible pavements with satisfactory properties that can be used on areas with heavy loads.

Experience from using semi-flexible pavement materials has shown that the material is fuel resistant. Even though the bitumen in the composite pavement is not fuel resistant, the semi-flexible pavement material has shown to be fuel resistant. Another important property of semi-flexible pavement materials is the dense surface that results in an impermeable pavement. This means that liquids, such as de-icing agents used in airports, cannot penetrate into the pavement. This is one of the reasons why the pavement is suitable on de-icing platforms in airports where large amounts of liquids are spread on the airplanes and thus on the pavement.

3 CONSTRUTION OF SEMI-FLEXIBLE PAVEMENTS

Use of traditional equipment for the construction of asphalt pavement does the construction of semi-flexible pavements. The open graded asphalt is laid by use of traditional asphalt pavers and the layer is compacted using static steel wheel roller compacters. It is of great importance that the open graded asphalt is not compacted too much because the requirements of the air voids shall be obtained in the compacted asphalt material. In order to obtain the requirements to the Powder Index, the mortar needs space to penetrate.

The semi-flexible pavement is normally constructed on an asphalt binder course with special properties to sustain heavy-duty loads. The asphalt binder course shall have properties that minimises the possibility of rutting, as this is the most often observed damage on semi-flexible pavements after traffic has been opened. Rutting is observed to take place in the bituminous binder course. Another method is to use cement-stabilised gravel or lean mix concrete. Hereby, the possibility of rutting is minimised but reflective cracking can then be a problem. Larger thickness of the semi-flexible pavement is then needed. This method is often used at indoor facilities where the temperature is nearly constant. Furthermore, the introduction of steel reinforcement enables the use of semi-flexible pavements on bituminous courses with less strength than mentioned above. The steel reinforcement is placed on the old asphalt surface and sprayed with a bituminous tack coat. The open graded asphalt is then constructed on the steel reinforcement net. Example of laying asphalt on steel reinforcement net is shown in figure 3.

Figure 3 Laying of open graded asphalt on steel reinforcement net

The micro silica mortar is normally delivered as powder in bags. The mixing of the powder with water is then done on site in accordance with the producer's description.

The spreading of the mortar is most often performed by hand or small, motorised vehicles, maximum 48 hours after laying of the open graded asphalt pavement. It is of great importance that the mortar is filled to the bottom of the open graded asphalt material. Visual inspection and handling skills are therefore very important.

The weather conditions when performing the spreading of the mortar are also important as too high temperatures can result in drying of the mortar with the result of too fast hardening of the micro silica mortar. To prevent too much drying of a newly spread mortar, curing of the surface is often applied.

Rain, however, also gives a poor finished material due to water in the pavement that has to been displaced by the mortar and thus a risk for poor penetration of mortar to the bottom of the open graded asphalt. The spreading is, therefore, a difficult procedure where much care shall be taken.

Semi-flexible pavement materials can be laid in different thickness depending on the traffic. When constructing more than approximately 70 mm, the construction of the open graded asphalt should be done in two layers. The spreading of the micro silica is, however, done in one operation. Experience has shown that if the open graded asphalt material is designed correct and constructed properly, the penetration of the mortar can be done for up till 150 mm with good results where the bottom of the asphalt is filled with mortar. In figure 4 an example of spreading mortar is shown.

Figure 4 Spreading of micro silica mortar on open graded asphalt, (Densit A/S, 2000).

The curing time for semi-flexible pavements is 24 hours at 20 ºC. This means that areas where semi-flexible pavements are constructed can, depending on the temperature, be opened for traffic approximately one to two days after the mortar is applied. Compared to cement concrete the curing time is thus very short.

An advantage of semi-flexible pavements is that it can be constructed without joints because the only cracks that are introduced in the pavement are micro cracks. Larger cracks are avoided due to the flexibility of the pavement that can absorb the movements from temperature fluctuations. Thus the maintenance cost of the pavement is reduced, as joint materials shall not be replaced every three to five year.

The finished surface of the semi-flexible pavement can be treated in various ways. Often the hardened surface is shot blasted in order to expose the aggregates of the asphalt material. Other methods include spreading of fine sand before the mortar is developing skin on the surface or by scraping the surface thoroughly after spreading of mortar. All these methods are used in order to obtain a satisfactory friction on the wearing course. Experience shows that similar friction to traditional asphalt wearing courses can be obtained, and the durability of the skid resistance is also similar to asphalt wearing courses.

4 DURABILITY AND PROPERTIES

4.1 Stiffness Modules

Semi-flexible materials have much higher Stiffness Modules than traditional flexible pavement materials such as asphalt. The high stiffness modulus is due to the presence of micro silica mortar in the pavement material. The stiffness module of semi-flexible materials is approximately twice the module of traditional asphalt materials.

A high stiffness modulus enables the use of semi-flexible materials for heavy-duty pavements due to smaller thickness of the total pavement. Because the semi-flexible pavement is used as a wearing course, the total thickness of the pavement can be reduced significantly.

The stiffness modulus of the semi-flexible pavement material depends on the temperature similar to traditional asphalt materials. The presence of bitumen in the material results in similar relationships between temperature and stiffness modulus as for traditional asphalt materials. An example of this relationship is shown in figure 5 where the stiffness modulus is determined at three different temperatures. The stiffness modules are determined on laboratory manufactured test samples. The test method used is the Indirect Tensile Stiffness Module test procedure. The results in figure 5 show that there is a linear relationship, in the shown temperature interval, between the temperature and stiffness modules for semi-flexible pavement materials.

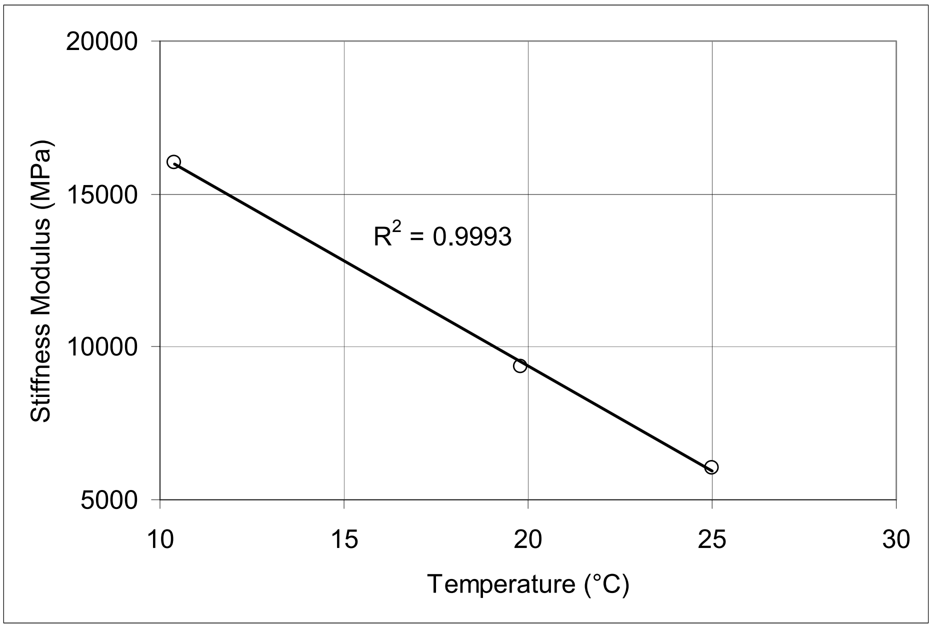

Figure 5 Indirect Tensile Stiffness Modulus at loading frequency 10 Hz on semi-flexible pavement materials depending on testing temperature.

Adding steel reinforcements increases the stiffness modulus. Laboratory experiments using 4-point bending beam test on semi-flexible pavement samples show that the stiffness modulus increases up to 70 % compared with semi-flexible pavement materials without steel reinforcements. Experiments have shown that the largest increase in the stiffness modulus is achieved when the steel reinforcement is placed in the bottom of the layer. Table 1 shows results from the 4-point bending determination of the stiffness modulus of samples with and without introduction of steel reinforcement.

	Without steel reinforcement	With steel reinforcement
Stiffness Modulus (MPa)	6,180	10,540

Table 1 Results from 4-point bending beam determination of stiffness modulus at 25 °C.

4.2 Rutting Resistance

The rutting resistance of semi-flexible pavement materials are significantly better compared to traditional asphalt pavement materials. This is also one of the reasons that the material is suitable for use on heavy-duty loaded areas.

In order to show this increased rutting resistance and the influence of adding steel reinforcements to the pavement layer a laboratory investigation was initiated. Laboratory samples consisting of three different structures were prepared. Table 2 summarised the different pavement structures. It shall be noted that the choice of a low-grade asphalt as the base material was made in order to investigate the influence of the different wearing courses better. The asphalt wearing course in the reference test is Asphaltic Concrete. The test was conducted at 60 °C using the Hamburg Rutting Tester.

	Sample no. 1	Sample no. 2	Sample no. 3
Wearing Course	40 mm Asphaltic Concrete	40 mm Semi-flexible without reinforcement	40 mm Semi-flexible with reinforcement
Base Course	80 mm low-grade asphalt	80 mm low-grade asphalt	80 mm low-grade asphalt

Table 2 Summary of different types of asphalt structures used in rutting determination.

In figure 6, the results of the rutting test are shown. As it appears from the figure, both types of Semi-flexible pavement structures show significantly higher rutting resistance compared to traditional asphalt materials. Furthermore, the introduction of steel reinforcement at the bottom of the Semi-flexible wearing course increases the rutting resistance even more.

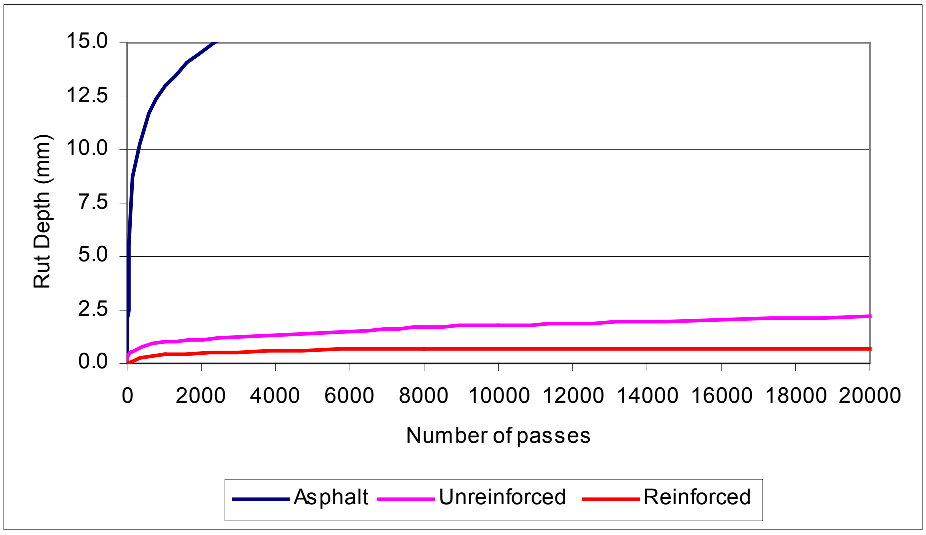

Figure 6 Results from the determination of rut depth of different types of pavement structures with and without steel rein-forcement in the bottom of the Semi-flexible wearing course

In order to illustrate the difference between the three types of tested pavement structures at the end of testing, please refer to figure 6 where a picture showing the samples is presented.

Figure 7 Comparison of the three different pavement structures at the end of testing. In the front is the asphalt wearing coursed, in the middle the semi-flexible wearing course without steel reinforcement and in the back the semi-flexible wearing course with steel reinforcement.

4.3 Fatigue Life

An example of the fatigue life of semi-flexible pavement materials is shown in figure 8. Samples used in the determination of the fatigue curve are laboratory produced, which results in samples with homogeneous properties such as air voids and degree of air voids filled with mortar. The test method used is the Indirect Tensile Fatigue Test. For comparison, an example of a traditional Asphaltic Concrete (AC) pavement material is also shown in figure 8.

As it appears from figure 8, the semi-flexible materials are less sensitive to traffic compared to the traditional Asphaltic Concrete. This also indicates that the semi-flexible pavement material is suitable in pavements with heavy-duty loads because heavy loads generate large strain values in the pavement.

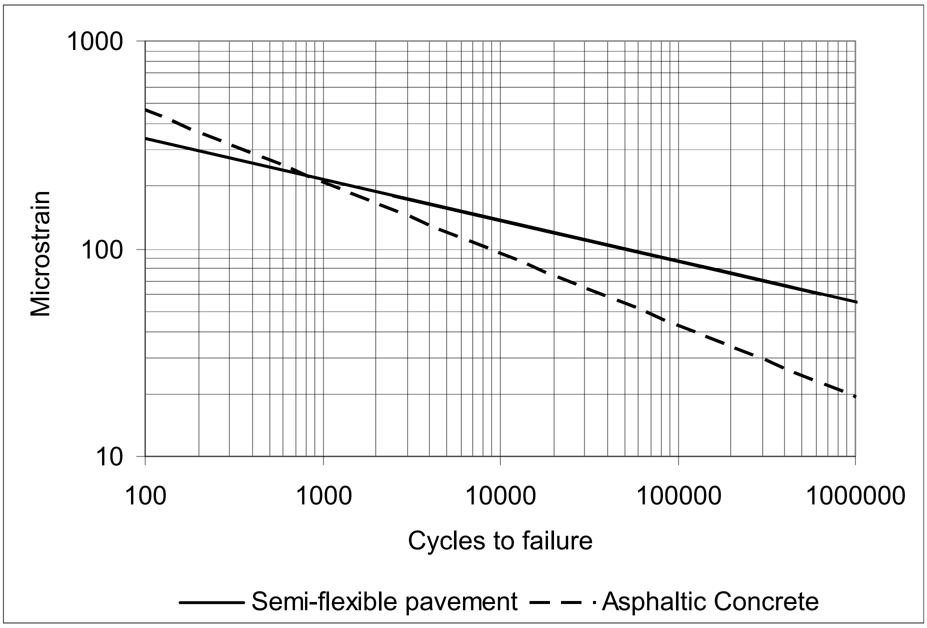

Figure 8 Indirect Tensile Fatigue test at loading frequency of 10 Hz on cores of laboratory produces semi-flexible pavement materials compared with asphaltic concrete.

4.4 Thin Sections

RAMBOLL has performed studies of semi-flexible pavements by use of the Thin Section technique. This test procedure enables investigations on pavement materials in detail.

Thin Sections are produced from samples of pavement materials for both semi-flexible pavement materials and traditional asphalt materials. A Thin Section is produced by taking a core and impregnated it with epoxy under vacuum. By doing this, all the air voids are filled with epoxy. From the sample with all air voids filled, a smaller sample is cut and polished on a diamant pad. The result after cutting and polishing is a sample that is approximately 20 μm thick, and investigations under microscope can start. Examples from investigations on semi-flexible pavement materials are shown in figures 9 and 10.

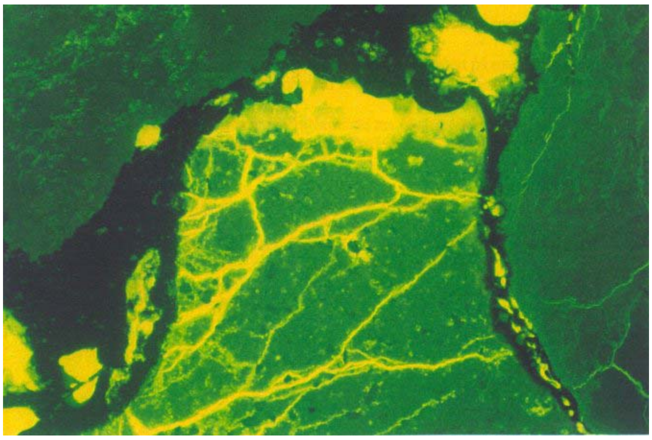

Figure 9 Image of thin section of ten years old semi-flexible pavement material. The image represent approximately 4.2 x 2.7 mm

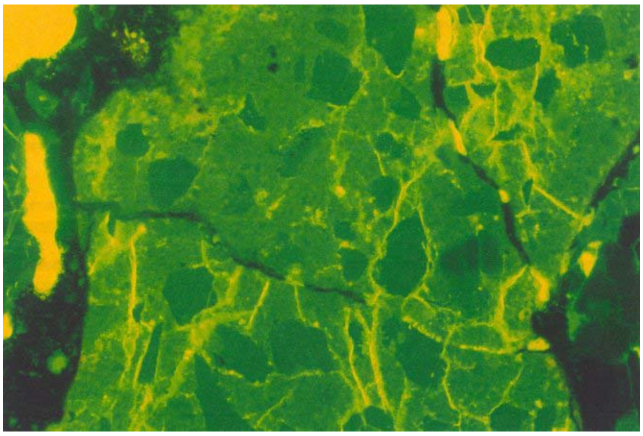

Figure 10 Image of thin section of a one-year-old semi-flexible pavement material. The image represent approximately 1.64 x 1.1 mm

Figure 9 shows a picture of a ten years old semi-flexible pavement, and figure 10 shows a picture of a one-year-old pavement. Both pavements have been exposed to traffic during the lifetime. Thus, the pavement shown in figure 9 has been exposed to approximately ten times the traffic than the material shown in figure 10.

By comparing the two pictures, it appears that the amount of micro cracks is not significantly larger in the ten years old pavement than in the picture of the one-year-old pavement. This indicates that micro cracks are more depending on the constructing quality than on the exposed traffic. It is very important that the mortar is filled to the bottom of the open graded asphalt material. If this is not the case, micro cracks will develop very soon after the pavement has been opened to traffic, and the possibility of developing larger cracks is increased.

5 DESIGN EXAMPLES

Semi-flexible pavements have been used for numerous heavy-duty pavements such as aircraft apron areas and bus terminals. Experience in airports comprises among others Denmark, Latvia, USA, Norway, Netherlands, Germany, Sweden and Singapore. In Denmark, the material has out-competed cement concrete on aprons, due to its low initial construction costs and low maintenance costs.

For indoor pavement, the thin, semi-flexible wearing course would traditionally be placed on a cement stabilised base course, which has received dynamic compaction to introduce micro cracking. For outdoors pavements, the thicker, semi-flexible wearing and binder course will be placed on a bituminous base or on dynamic compacted cement stabilised base course. On old asphalt layers with reduced strength, the introduction of steel reinforcement will increase the quality of the pavement structure. Examples of pavement structures for industrial flooring (lean mix concrete) and airport apron (bituminous base course) are given below.

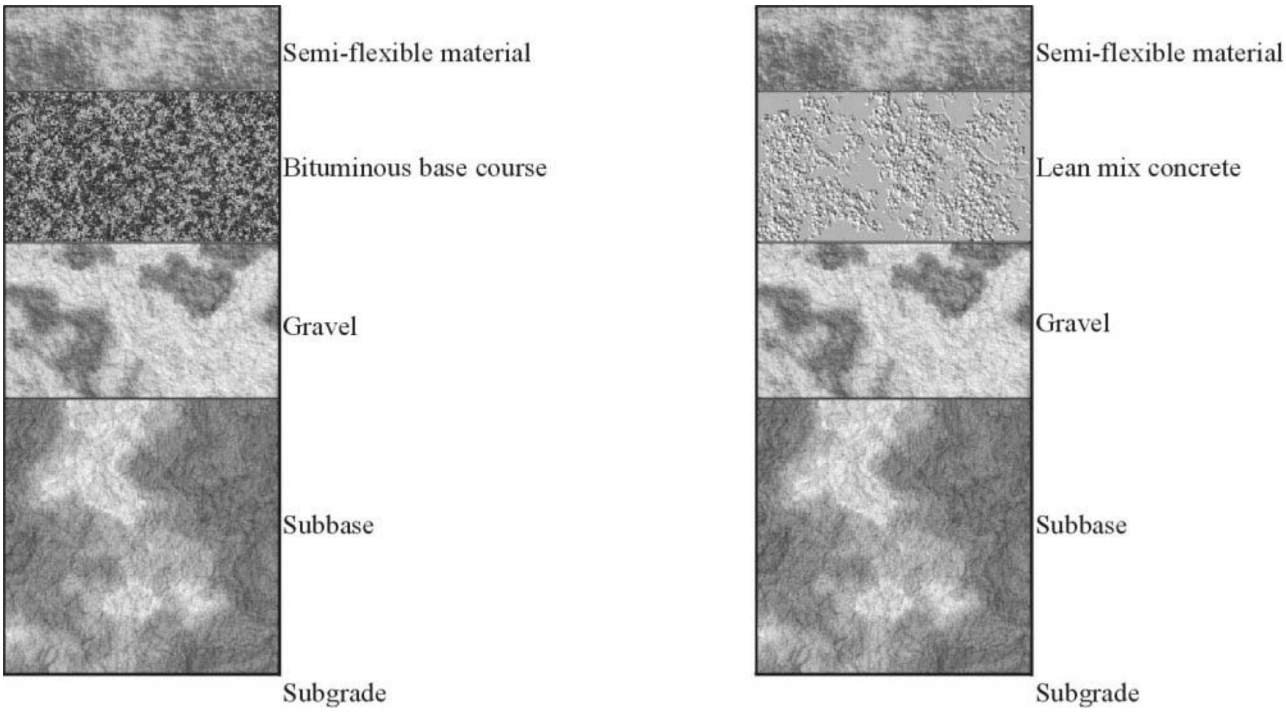

Figure 11 Design examples of semi-flexible pavement with bituminous base course and lean mix concrete as base.

Semi-flexible pavements are well suited for use in mechanistic design methods used in many countries around the world. The strength of the material can be set to 8,000 MPa for normal load frequencies (33 Hz). Pavements can thus be designed for each particular situation (load, subgrade strength, material properties) using the local derived empirical relationships.

Experience has shown, that apron pavements serving the very heaviest aircrafts might have, depending on the situation, a risk of showing premature rutting. Investigations have shown that this rutting occurs in the bituminous base course. Hence the latest development in the pavement structure is increasing the thickness of the semi-flexible material to as much as 150 mm, or incorporating inlay of reinforcements to increase the tensile stress properties. So far, experience shows that the high strength cement mortal smoothly penetrates to the bottom of the layer, even when 150 mm thick. Another direction of development for outdoor pavements is replacing the bituminous base course with cement stabilised base courses. Such a structure would be free of risk of rutting. For both directions of development the preliminary results are positive.

Furthermore, especially the results of the rutting test on semi-flexible pavement materials with steel reinforcements show that the pavement materials can be used on areas where the existing pavement does not have sufficient strength to accommodate for the applied load. This means that replacement of existing wearing courses with high rutting with semi-flexible wearing course containing steel reinforcement may be advantageously conducted. Hence, there exists a suitable solution to repair old low strength pavements where heavy-duty loading is applied.

6 CONCLUSION

The use of semi-flexible pavement materials on areas designed for heavy-duty traffic has several advantages than can be summarised as follows:

- Semi-flexible pavements can be constructed in layers from 35 mm to 150 mm, which enables design for particular situations depending on loads and other factors.
- The pavement is constructed without joints, which reduces the maintenance cost significantly compared to other heavy-duty pavement types.
- The durability and fatigue life of the pavement is very good. The development of cracks on the surface is limited, and only micro cracks are introduced in the pavement.
- The rutting resistance of the pavement is high. This is the case especially when steel reinforcement is introduced at the bottom of the wearing course.
- Semi-flexible wearing courses can be advantageously used to repair existing pavement with low rutting resistance in the upper layers.
- Semi-flexible pavement surfaces can be treated in order to obtain sufficient friction and experience shows that the skid resistance is obtained for more than ten years.
- Semi-flexible pavements are fuel resistant and impermeable against de-icing agents and other liquids.
- The whole construction of semi-flexible pavements has shown to be cost efficient compared to other pavements for heavy-duty loading.

7 REFERENCES

Densit A/S, “Densiphalt® Handbook”, 2000