THE RESISTANCE OF MODIFIED BITUMINOUS FELTS TO WORKING TRAFFIC: THE ' WALK-ON-ABILITY'

by E.A.T. Trommelen and G.W.J. Heimerikx

Shell International Chemicals B.V.
Shell Research and Technology Centre, Amsterdam,
The Netherlands

Key words:

Roofing, SBS modified bitumen, Walk-on-ability, Working traffic, Indentation, Creep

Summary

Torching is one of the most widely used application methods for bituminous roofing felts. The heat/energy that is partly stored in the coating compound leads to a temporary softening, which in case of excessive working traffic may lead to aesthetical surface effects. The resistance of a compound to withstand such working traffic is often referred to as the 'walk-on-ability' which is currently ranked by the penetration value at 50°C.

In this study the validity of the penetration at 50°C as the single criterion to judge walk-on-ability has been investigated. This paper describes the evaluations of the rheological behaviour of SBS bituminous compounds under stress at moderately elevated temperatures, i.e. penetration, indentation and recovery and creep tests. The loading conditions have been chosen such that a realistic comparison could be made with the actual load exerted upon the roof by an average person.

The penetration and indentation tests at 50°C give an indication on deformation for short loading times, but the penetration test does not provide any information on the permanent deformation: relaxation after an indentation test at 50°C shows that within a couple of minutes complete resilience and hence absence of foot prints within minutes, in which cases the softer base compounds allow a quicker resilience to take place.

Both penetration and indentation tests do not provide any information on the permanent deformation regarding longer

constant loading; creep tests have to be carried out and there is no univocal correlation between the penetration or the indentation test and the resistance to creep at longer loading times.

Zusammenfassung

Das Arbeiten mit offener Flamme ist eine der am weitesten verbreiteten Befestigungsmethoden für bituminöse Dachbahnen. Die Wärme bzw. die Energie die dadurch der Mischung zugeführt wird, bewirkt eine zeitweise Erweichung der Bahn und kann bei Durchführung der Arbeiten und der damit verbundenen Belastung zu einer unerwünschten Veränderung der Oberfläche führen. Die Widerstandskraft einer solchen Mischung gegen Deformierungen, allgemein auch als ´walk-on-ability´ bezeichnet, wird gegenwärtig mit den ermittelten Penetrationswerten (gemessen bei 50°C) korreliert.

In der vorliegenden Studie wird untersucht inwieweit nun der Penetrationswert bei 50°C als einziges Kriterium für die Bewertung der ´walk-on-ability´ geeignet ist. Dieses Papier beschreibt das rheologische Verhalten von bituminösen S-B-S Mischungen bei entsprechender Belastung und geringfügig erhöhten Temperaturen, wobei Penetrations-, Kugeldruck- und Rückstellelastizitätstests sowie Kriechtests durchgeführt wurden. Bei den Bedingungen wurde darauf geachtet, dass ein realistischer Vergleich mit der gängigen Praxis bei Arbeiten auf dem Dach gewährleistet ist.

Die Penetration und der Kugeldrucktest bei 50°C zeigen die durch kurzzeitige Belastung entstehende Deformierung auf, wohingegen keine Aussage über eine dauerhafte Deformierung getroffen werden kann: Im zeitlichen Verlauf nach einem Kugeldrucktest bei 50°C zeigt sich, dass innerhalb weniger Minuten durch die Rückstellelastizität keine Fussabdrücke mehr sichtbar sind. Dieser Vorgang wird durch eine weichere Mischungsbasis begünstigt.

Sowohl Penetration als auch der Kugeldrucktest lassen keinerlei Rückschlüsse hinsichtlich des Ausmasses einer dauerhaften Deformation bei längerer, konstanter Belastung zu; hierfür müssen Kriechtests durchgeführt werden. Hierbei zeigt sich, dass keine eindeutige Korrelation zwischen Penetration oder

Kugeldrucktest und der Widerstandskraft gegen das Kriechverhalten bei längeren Belastungen besteht.

Résumé

La pose au chalumeau est l'une des méthodes d'application les plus répandues pour les membranes bitumineuses d'étanchéité. La chaleur/énergie qui est partiellement stockée dans la masse d'enrobage , conduit à un ramollissement temporaire , qui , en cas de passage fréquent , peut provoquer des marques inesthétiques sur la surface. La résistance d'une masse d'enrobage pour supporter ce type de contrainte est souvent référencer comme la propriété de résistance au piétinement (« walk-on-ability » en anglais) qui est mesurée par la pénétration à 50°C.

Dans cette étude, la validité de la mesure de pénétration , comme seul critère pour juger de la résistance au piétinement , a été étudiée . Cet article décrit l'évaluation des comportements rhéologiques de formulations avec des polymères SBS, sous contrainte et à une température modérément élevée. Il présente également les tests de pénétration, poinçonnement, retour élastique, et de torsion , établis, de manière, à ce que les comparaisons soient possibles avec la charge exercée sur le toit par le poids moyen d'un poseur.

Les tests de pénétration et poinçonnement , à 50°C, donnent une indication de la déformation pour une courte durée de contrainte, mais le test de pénétration ne donne aucune information en ce qui concerne la déformation permanente . En effet , après quelques minutes, la relaxation après un test de poinçonnage à 50°C montre une résilience totale (avec à terme une absence de trace de pas) ; à noter que, les masses d'enrobés les moins dures montrent une résilience plus rapide.

Les tests de pénétration et poinçonnement ne fournissent pas d'information sur la déformation permanente , pour des temps de contrainte plus élevés. Pour cela des tests de torsion doivent être effectués, bien qu'il n'y ait pas de corrélation entre les tests de pénétration ou de poinçonnement et la résistance à la torsion pour des temps des contraintes plus élevés .

Riepilogo

La cementazione fine rappresenta uno dei metodi più diffusamente utilizzati come cartonfeltro per manti di copertura bituminosi. Il calore / energia che in parte si deposita nei composti da rivestimento genera un ammorbidimento temporaneo che, quando il calpestio di utilizzo diventa particolarmente intenso, può avere conseguenze di carattere estetico sulla superficie. La resistenza che un materiale composto oppone a detto calpestio di utilizzo è spesso denominata “resistenza all’usura da calpestio” e di norma viene stimata secondo il valore di penetrazione a 50°C.

Oggetto di questa ricerca è verificare la validità del criterio della penetrazione a 50°C come unico criterio per stabilire la resistenza all’usura da calpestio. Il presente documento presenta le valutazioni delle prestazioni dal punto di vista della reologia dei composti al bitume SBS sotto stress a temperature moderatamente elevate, ossia i test su penetrazione, intaccatura e riassestamento, oltre alla deformazione. Sono state scelte condizioni di carico tali da poter effettuare un confronto realistico con il carico effettivo esercitato sul manto di copertura da una persona di corporatura media.

I test di penetrazione e intaccatura a 50°C forniscono indicazioni sulla deformazione per carichi di breve durata, ma il test di penetrazione non fornisce alcuna informazione sulla deformazione permanente: l’attenuazione dopo il test di intaccatura a 50°C dimostra che entro un paio di minuti si ha una resilienza completa e pertanto, entro pochi minuti, la totale assenza di impronte, casi questi nei quali i componenti a base più soffice consentono una resilienza più veloce.
Sia i test di penetrazione che di intaccatura non forniscono alcuna informazione sulla deformazione permanente relativa a carichi costanti di durata più lunga; è necessario effettuare i test sulla deformazione e non vi è una correlazione univoca tra i test di penetrazione o di intaccatura e la resistenza alla deformazione con tempi di carico più lunghi.

Introduction

High mechanical demands imposed on waterproofing systems by well insulated lightweight roof constructions have led to modification of bituminous roofing felts with polymers. From a variety of polymers tested in a wide range of different bitumens, Styrene-Butadiene-Styrene (SBS) block copolymers have shown to be one of the two commercially successful types of polymers in this application.

The physical nature of SBS is reflected in the properties of bitumens modified with these polymers: they have a balanced set of properties providing low temperature flexibility, flow resistance at high temperatures and a high extendability and elastic recovery for fatigue resistance and durability.

To achieve this premium quality a content of 12% w/w SBS, i.e. on bitumen + SBS, is commonly used. The extended range of SBS polymers available nowadays allows bituminous roofing formulations to be tailored to the needs required [1]).

The most common way to apply the felts on the roof is by means of torching. During torching the heat/energy is partly stored in the coating compound which leads to a temporary softening, which in case of excessive working traffic may lead to aesthetical surface effects. The resistance of a compound to withstand such working traffic is often referred to as the 'walk-on-ability' which is currently ranked by the penetration of the compound at 50°C.

In this study the validity of the penetration at 50°C as the single criterion to judge walk-on-ability has been investigated. This paper describes the evaluations of the rheological behaviour of SBS bituminous compounds under stress at moderately elevated temperatures, i.e. penetration, indentation and recovery and creep tests. The loading conditions have been chosen such that a realistic comparison could be made with the actual load exerted upon the roof by an average person. The tests as described above have all been carried out at a temperature of 50°C to obtain a clear comparison with the results of the penetration test at 50°C.

Also, on the basis of the results obtained, ways have been explored how to improve the walk-on-ability of the compounds. The following components have been used and varied to investigate the effects on the performance properties related to 'walk-on-ability':

- bitumen hardness
- type of SBS polymer
- the presence or absence of filler

Besides a standard SBS polymer roofing grade, a recently introduced IPD (Improved Processing and Durability) [2,3]) SBS roofing grade was selected as this particular grade had also shown to have interesting rheological properties.

1. Polymer modified blends

6 Master batches with 12% of each of the 2 SBS grades in three types of commercially available bitumen, i.e. B 45/60, B 80/100 and B 160/210, have been prepared. These blends were made with a Silverson L4R high shear mixer. The bitumen was heated to 160°C and subsequently the polymer was added. Upon blending, the temperature increased to 180°C, which is caused by the energy input from the mixer. Blending at this temperature was continued until a homogeneous blend was obtained which was monitored by fluorescence microscopy.

With these master batches compounds were prepared adding the filler under low shear stirring at a temperature of 180°C.

2. Rheological performance properties

It is realised that immediately after torching there will be a temperature gradient in the felts, which makes the selection of a reliable testing temperature a bit questionable. However, as in the past always reference has been made to the penetration value at 50°C, this temperature was also adopted for the other tests. The possible effects associated with unprofessional torching (over-heating) have obviously not been taken into account.

2.1 Test methods

A standard evaluation on the blends without filler, i.e. the determination of softening point, viscosity, DIN flow resistance and cold bend [4]), has been carried out.

The penetration at 25°C and 50°C of each compound in this study was also determined.The load applied on the surface of a compound during a penetration measurement calculated is as follows:

The cone tip diameter of the needle used is 0.15 mm (as reported in the calibration report and defined in ASTM D5-94). The surface of the needle ($0.25 \times \pi \times d^2$) is 0.0177 mm^2. The total load applied during the measurement, i.e. the weight (50 g) and bar, amounts 100 g.

Therefore, the actual load is: $100 \div 0.0177 = 5650$ g/mm^2 = 56500 kPa.

However, immediately after the start of the experiment the surface in contact with the compound rapidly increases and hence is the stress reduced. The average stress for a penetration of 60 dmm has been estimated to be 30 kPa.

The indentation and resilience

If the surface of an average shoe size is 210 cm^2 (30 x 7 cm) and the weight of an average person is 80 kg, the load which is exerted on the roof ($80 \div 210 = 0.394$ kg/cm^2) is 38 kPa.

The experiments were carried out on the compounds in penetration cups. On the surface of the compound a round flat metal cylinder was placed with a diameter of 1.3 cm. In this study the indentation tests have been carried out by applying two different loads, i.e. 0.5 kg and 1 kg. The actual loads exerted upon the compounds are therefore: 38 kPa and 76 kPa.

Like in a penetration test the bar was released for 5 seconds applying the loads upon the compounds. Subsequently the level of indentation was determined, the bar (loads) removed from the indentation surface and the elastic recovery determined in time.

Creep tests were done for each compound at 50°C applying various loads.

The creep test has been performed with a Haake RT20 Rotoviscometer using a parallel plate configuration. The diameter of the upper plate was 8 mm, while the distance between the plates was 1 mm. The initial thickness of the samples used amounted 1.5 mm. Before the start of the measurement the samples were trimmed. The creep tests were carried out applying a constant load of 40 kPa, 20 kPa, 10 kPa or 5 kPa. The compliance J (1/Pa) as a function of time has been determined for each compound.

2.2 Penetration

The 'walk-on-ability' is often described by the penetration value at 50°C. If the penetration value exceeds 100 dmm the product is often rated 'too soft' implying an insufficient resistant to deformation.

2.2.1 Influence of type of bitumen and polymer

The results of the standard evaluation of the SBS and IPD compounds without filler incorporated are given in Table 1.

Although the results of a complete evaluation are reported, the emphasis in the evaluation is put on the results obtained with the penetration measurements.

Table 1. Initial rheological performance properties of 12% SBS in bitumen.

Polymer	SBS	SBS	SBS	IPD	IPD
Bitumen	B45/60	B80/100	B160/210	B80/100	B160/210
Pen Bit. 25°C	41	82	193	82	193
Blend No.	99/50110	99/50111	99/50112	99/58124	99/58123
Pen 25°C, dmm	19	32	48	31	47
Pen 50°C, dmm	80	90	104	94	108
$T_{R\&B}$, °C	134	131	125	147	140
Visco, 180°C					
20 s^{-1}	3.2	2.0	1.9	3.8	2.3
100 s^{-1}	2.5	1.6	1.4	3.0	1.7
Cold bend, °C	-5	-30	-45	-10	-25
DIN flow, °C	110	95	90	125	115

The results obtained on the standard SBS compounds are in line with what one would expect: i.e. with a harder bitumen the penetration value decreases, while the blend viscosity and the softening point increase. The influence of a harder bitumen is also reflected by a poorer low temperature flexibility and an improvement in high temperature flow resistance.

With the IPD compounds a similar effect as described above has been found. With the IPD compounds, providing high softening points R&B, slightly higher penetration values at 50°C have been found in comparison with those of its SBS equivalent.

It can be concluded that the use of a harder bitumen will improve the penetration value at 50°C, as was expected. The penetration at 50°C of an IPD blend without filler is slightly poorer in comparison with that of its SBS equivalent.

2.2.2 Influence of filler

The penetration values found at both temperatures for the SBS and IPD compounds with and without 30% filler (limestone) incorporated are given in Table 2.

Table 2. Penetration values at 25°C and 50°C for each SBS compound.

Polymer	SBS	SBS Filler	SBS	SBS Filler	SBS	SBS Filler	IPD	IPD Filler	IPD	IPD Filler
Bitumen	B45/60	B45/60	B80/100	B80/100	B160/210	B160/210	B80/100	B80/100	B160/210	B160/210
Blend No.	99/50110	99/50157	99/50111	99/50158	99/50112	99/50159	99/58124	99/58146	99/58123	99/58145
Pen at 25°C	19	11	32	21	48	33	31	18	47	30
Pen at 50°C	80	58	90	82	104	94	94	76	108	96

Obviously, if filler is incorporated a harder compound is obtained, leading to a significant decrease in the penetration value. In all cases, the compounds with filler were below the value of 100 dmm.

It can be concluded that the use of filler results in a significant reduction of the penetration of the final compound.

2.3 Indentation and resilience

Although the penetration at 50°C, applying an average load of 30 kPa, is often used to determine the 'walk-on-ability', it is difficult to imagine that this measurement under these conditions represents the actual working conditions during application of the roofing felt.

With an indentation test, as described in the section 'test methods', a more realistic view of the material behaviour when applying a certain load can be obtained. With these measurements the level of indentation and subsequent resilience of the material can be determined under realistic loading conditions.

2.3.1 Influence of bitumen, type of polymer and filler

The results of the initial indentation at 50°C found versus the penetration at 50°C of the SBS and IPD compounds with and without filler present for both loading conditions are reported in Figure 1.

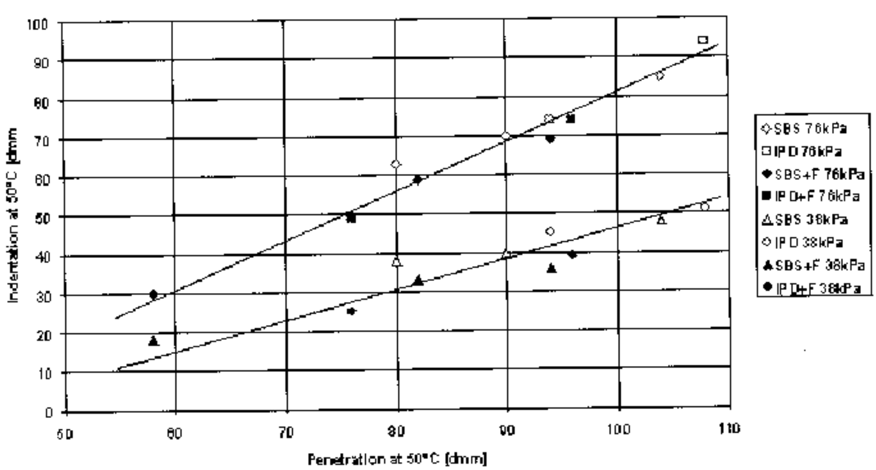

Figure 1. Initial indentation versus penetration at 50°C.

A linear relation between the level of indentation and the penetration value at 50°C has been found, i.e. a compound with a higher penetration value shows a higher level of indentation. The effect of filler is evident on both the penetration and indentation, especially in case a harder bitumen (B45/60) is used as base bitumen. Furthermore, the relation between the penetration and indentation appears to be independent on the type of SBS polymer present in the compound. If a higher load is applied (76 kPa) a higher initial indentation is found, which could be expected.

It can thus be concluded that the level of indentation is related to the penetration value of the compound. Therefore, both test methods will provide an indication of the deformation under normal working conditions. However, a possible permanent deformation can only be determined after resilience, which is part of the indentation test and can not be determined by the penetration test.

The resilience of a compound, e.g. in case of foot printing, is a quality parameter providing information on possible aesthetical surface effects after application of the felt on the roof.
In Figure 2 the resilience of two SBS and IPD compounds including filler applying an excessive load of 76 kPa are reported. With the SBS compounds a comparison is made between the blend with the lowest initial indentation value (with bitumen B45/60) and the highest indentation value (with bitumen B160/210). In case of the IPD compounds a comparison is made between the blend with bitumen B80/100 and B160/210.

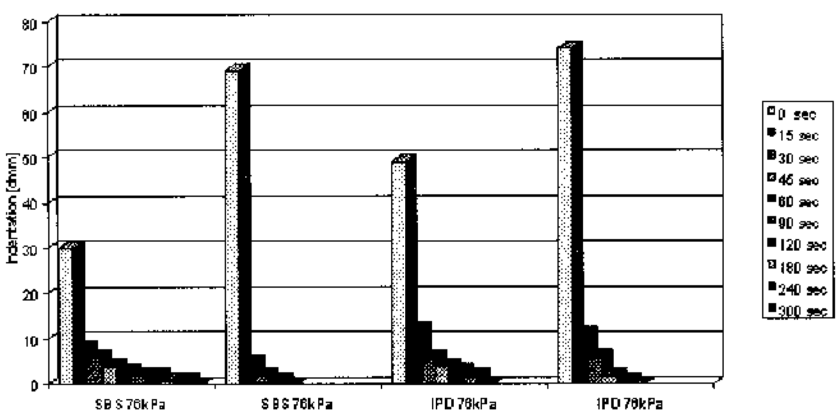

Figure 2. Indentation and recovery of SBS and IPD compounds including filler.

The above results show in all cases a complete recovery, even when an excessive load of 76kPa has been applied. The recovery is independent of the type of SBS polymer present in the compound. It can be concluded that with the compounds used in this study the resilience is independent of the penetration value of the compound, while it is remarkable that the recovery of a softer compound takes significantly less time, although the indentation is higher.

With these compounds no permanent deformation, i.e. aesthetical surface effects, are to be expected during application on the roof under normal working conditions. However, the indentation and resilience test provides information based on short loading times. In order to determine the material behaviour if exposed to longer loading times, creep tests have been carried out.

2.4 Creep test; deformation under constant stress

The creep test has been carried out to determine the resistance to deformation of a compound when a constant load is applied. This type of test will provide information of the material behaviour if a person or an object exerts a longer, shearing load on the roof, i.e. while standing on a sloped roof in which case more severe damage may be done to the felt.

2.4.1 Influence of bitumen and filler

In the following Figures 3 to 5 the compliance as a function of time applying different loads has been given for each SBS compound with filler present. With the SBS compounds the result of the particular compound without filler present applying a load of 40 kPa has also been given as a reference. The latter result has been reported by an open marker in the Figures.

In creep there are three stages to be recognised: the visco-elastic response is at first mainly elastic and gradually gets to an almost linear regime, in which the deformation is mainly of viscous nature. But it may also occur that, after the purely viscous deformation, the compound gets into a catastrophic phase, in which rapid deformation indicates the collapse of a network, in this case the SBS network. It is obvious that damage will take place during viscous deformation, but that it becomes significant in the catastrophic phase.

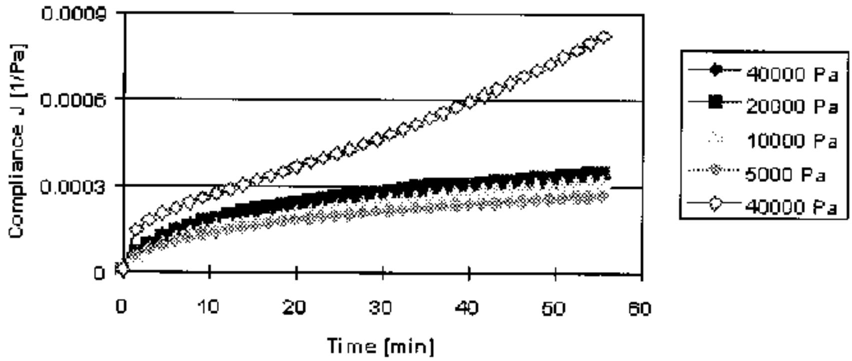

Figure 3. Compliance of SBS compound in B45/60 bitumen.

The resistance to deformation has been significantly improved with the introduction of 30% filler. With the blend with B45/60 bitumen and filler present, only a small effect on the creep has been found upon increasing the load. The low level of compliance increase found indicates a strong resistance to permanent deformation.

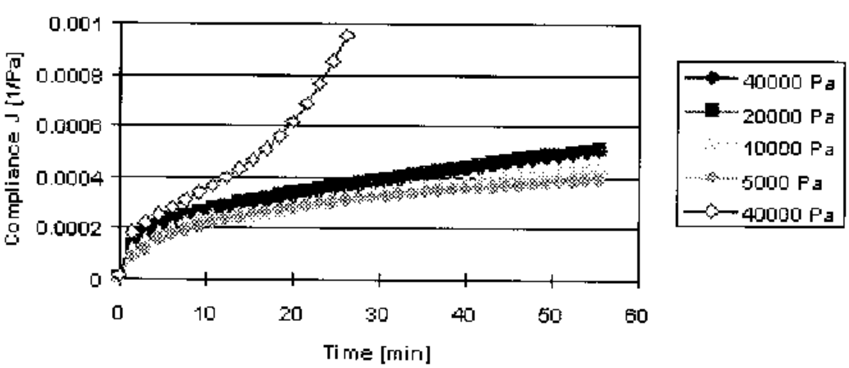

Figure 4. Compliance of SBS compound in B80/100 bitumen.

With this softer compound again a significant effect on the compliance has been observed if filler is incorporated. Still a minor effect on the compliance has been found upon increasing the load, while the shape of the curves are almost similar in comparison with those of the former compound. The unfilled compound gets fairly rapidly in the catastrophic phase.

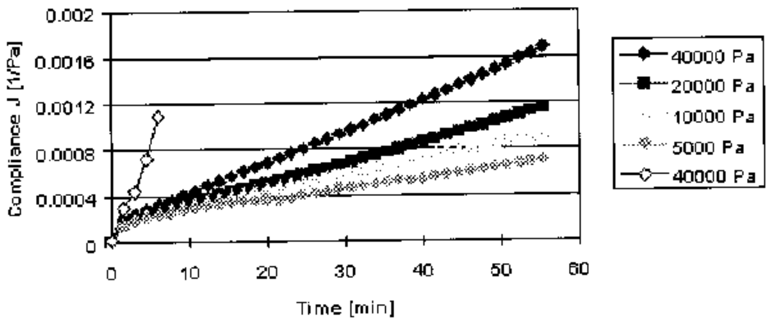

Figure 5. Compliance of SBS compounds in B160/210 bitumen.

With the softest base bitumen, the unfilled compound shows an almost immediate catastrophic behaviour and hence substantial permanent deformation. However, with filler present a major improvement has been established. This compound also shows a larger effect upon increasing the load and subsequently the shape of the curves shows a continuous creep in time.

The results found for the SBS compounds with and without filler tested in creep at a constant load of 40 kPa are given in Figure 6. In this Figure the compliance found after a short loading time of 6 minutes and after a longer loading time of 50 minutes are reported versus the penetration values found for these compounds at 50°C. The bottom line represents the compliance found after 6 minutes of constant load while the upper line shows the compliance found after 50 minutes.

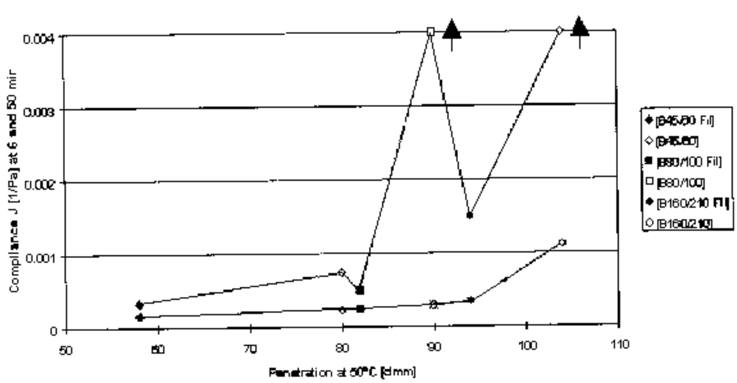

Figure 6. Compliance at 40 kPa of SBS compounds versus penetration at 50°C.

The results generated after a relatively short loading time, shows that with a softer compound a poorer resistance to deformation is found. These results are in line with the results reported on the penetration and indentation tests, which are tests that are carried out with extremely short loading times, compared to the loading times used in the creep test.

However, the results generated in the creep tests show that the resistance to deformation upon longer loading is not related to the penetration value found at 50°C. Higher penetration values at 50°C suggest that there will always be a poorer resistance to permanent deformation, like this is proven to be true for short loading. However, upon longer loading the Figure shows that in two cases an increase in the penetration value at 50°C does not lead to a poorer resistance to deformation: the unfilled compound with B45/60 bitumen (Pen 80) shows a poorer resistance to creep deformation in comparison with the softer compound with B80/100 bitumen and filler (Pen 82). This is also true for the unfilled compound with B80/100 bitumen (Pen 90) in comparison with that of the blend with B160/210 bitumen and filler (Pen 94).

Analyses on creep carried out with lower constant loading, i.e. 10 kPa, show a similar trend and behaviour as reported in Figure 6, albeit that the differences in compliance after short and longer loading times are smaller.

It must be noted that a comparison is made between compounds with and without filler and in different pen bitumens. However, if the penetration at 50°C of a compound is the only value which is used for a judgement in terms of walk-on-ability, such a comparison as listed above is justified.

It can be concluded that the use of filler has a significant effect on the resistance to deformation. The use of a harder bitumen also results in a better resistance to creep and a lower influence of the loading level value. However, it is shown that there is no univocal relation between the penetration at 50°C and the resistance to deformation subsequently upon longer loading.

2.4.2 Influence of type of polymer

In the following Figures 7 to 9 the compliance as a function of time applying different loads has been given for each IPD compound with filler. With the IPD compounds the result of the particular compound without filler under a load of 40 kPa has also been given as a reference. The latter result has been reported by an open marker in the Figure.

The shape of the curves found for the IPD blend in B80/100 bitumen can be compared with those reported for the SBS compound in B80/100 bitumen, see Figure 4. A similar influence on the creep when filler is incorporated is observed, while the slope of the line in the 'linear' regime is lower than with standard SBS.

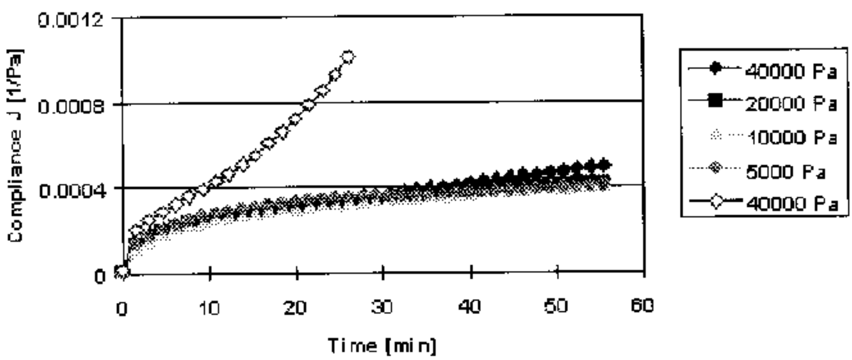

Figure 7. Compliance of IPD compound in B80/100 bitumen.

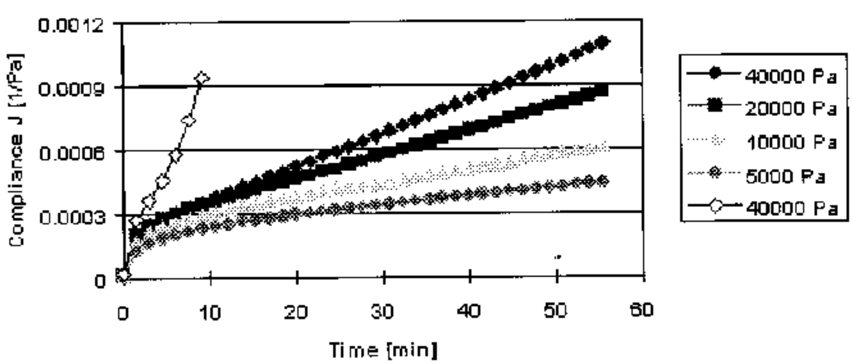

Figure 8. Compliance of IPD compound in B160/210 bitumen.

The compliance of the IPD compound in B160/210 bitumen shows a similar behaviour in comparison with those found for the SBS compound in B160/210 bitumen, see Figure 5, but again with a slower deformation.

In the next Figure 9 the relation between the penetration at 50°C of a compound and the resistance to deformation, as already described in Figure 6, has been given for each compound with filler incorporated at the typical working load of 40 kPa. The bottom line represents the compliance found after 6 minutes of constant load while the upper line shows the compliance found after 50 minutes. Furthermore, in this Figure the influence of the type of polymer present in the compound has been highlighted.

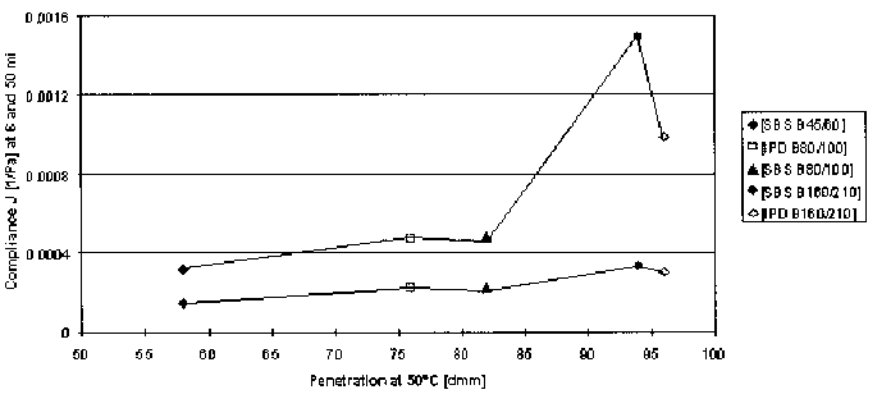

Figure 9. Compliance at 40 kPa of each compound versus penetration at 50°C.

The results reported in Figure 9 confirm that the level of the penetration at 50°C upon longer loading does not univocally relate to the resistance to deformation. Therefore, the penetration at 50°C only, provides insufficient, and in some cases misleading, information about the walk-on-ability.

It is for instance demonstrated that the use of an IPD polymer shows a better resistance to deformation in comparison with that found for a standard SBS polymer, e.g. SBS-IPD B160/210 (Pen 96) versus SBS B160/210 (Pen 94).

3. Conclusions and Recommendations

If the three test methods are evaluated the following conclusions seem justified:

- Walk-on-ability' in terms of resistance to deformation due to moving working traffic is fairly well described by both the penetration and the indentation at elevated temperatures.

- The penetration test does not provide any indication on the permanent deformation: relaxation after an indentation test at 50°C shows that within a couple of minutes complete resilience is achieved and hence there is absence of foot prints within minutes, in which cases the softer base compounds allow a quicker resilience to take place.

- Both test do not provide any information regarding longer constant loading and the permanent deformation; creep tests have to be carried out and there is no univocal correlation between the penetration or the indentation test and the resistance to creep at longer loading times.

The penetration of a compound can be influenced by the use of a harder base bitumen and by the presence of filler, which was expected.

The use of an IPD polymer shows a better resistance to deformation in comparison with that found for a standard SBS polymer.

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