THE USE OF VEGETABLE OIL IN ASPHALT MIXTURES, IN THE LABORATORY AND FIELD

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ABSTRACT

The first half of this paper explores the effect of blending a known quanity of vegetable oil (both virgin and used) with bitumen under controlled conditions to allow an understanding of the physical, mechancial and chemical properties to be developed. For the initial laboratory study a hard base bitumen 10/20 pen grade was selected, and blended with vegetable oil in order to replicate the properties of a straight run 40/60 pen grade (known henceforth as Vegetex binder for ease of explanation). Experiments have shown the Vegetex binder to be rheologicaly equivalent to a conventional straight run 40/60 pen. Asphalt mixes made with the Vegetex binder produced equivalent if not improved performance in the following tests: compactability, stiffness, fatigue, resistance to permanent deformation (wheel tracking), oven aging and water sensitivity.
The second half of this paper summarises the findings of the first live road trial of a Vegetex mixture that took place during October 2009 in Bedfordshire, UK. Overall the trial showed the Vegetex material to age significantly less (20%) than an equivalent control mix composed of a standard bitumen. No difference was also observed between the Vegetex and control sections in terms of texture depth and surface regularity. As a follow up, a visual assessment of the site was made 6 months after laying and the site was found to be in good condition with no early signs of deterioration.

Keywords: Vegetable Oil, Bitumen Fluxing, Asphalt Mixtures

1. BINDER TESTING

Previous work by the authors [1] has proved that vegetable oils were very compatible with straight run bitumens, that blending was a very simple process and that the oil does not affect the temperature susceptibility of the bitumens in any adverse way. The aforementioned work demonstrated that it is possible to modify a standard penetration grade bitumen to any other softer grade by carefully blending with vegetable oil, thus allowing the designer to customise a binder to any target viscosity or G* value. However, what the investigation did not attempt to prove was whether or not oil blended bitumen of a known grade will have equal performance to and be totally indistinguishable from an equivalent straight run bitumen. To achieve this objective, it was decided to convert a 10/20 pen straight run bitumen into a 40/60 pen grade by blending with vegetable oil (known henceforth as Vegetex 50).

A full sweep of rheological tests was henceforth carried out on the Vegetex 50 and the results compared directly with those from a conventional straight run 40/60 pen to identify any differences between the two binder types. The DSR tests reported below were performed under the following test conditions: controlled strain mode of loading, test temperatures ranging from 0 to 70°C in 5ºC increments, 0.01 to 10 Hz test frequency. For temperatures in the range 70 to 45°C, 25mm plate diameter and 1mm width were used. Temperatures in the range 45 to 0°C an 8mm plate diameter and 2mm width were used. The strain amplitude was kept within the LVE response (0.5 to 10%) as a function of complex modulus (G*) values. The results of G* and phase angle (δ) of the Vegetex 50 and the conventional 40/60 pen bitumen are shown in figure 1. Testing was carried out on the virgin samples and on samples following short (RTFOT) and long term oven aging (PAV). The figure clearly shows that rheologically, it would not be possible to distinguish between the oil blended and the straight run samples.

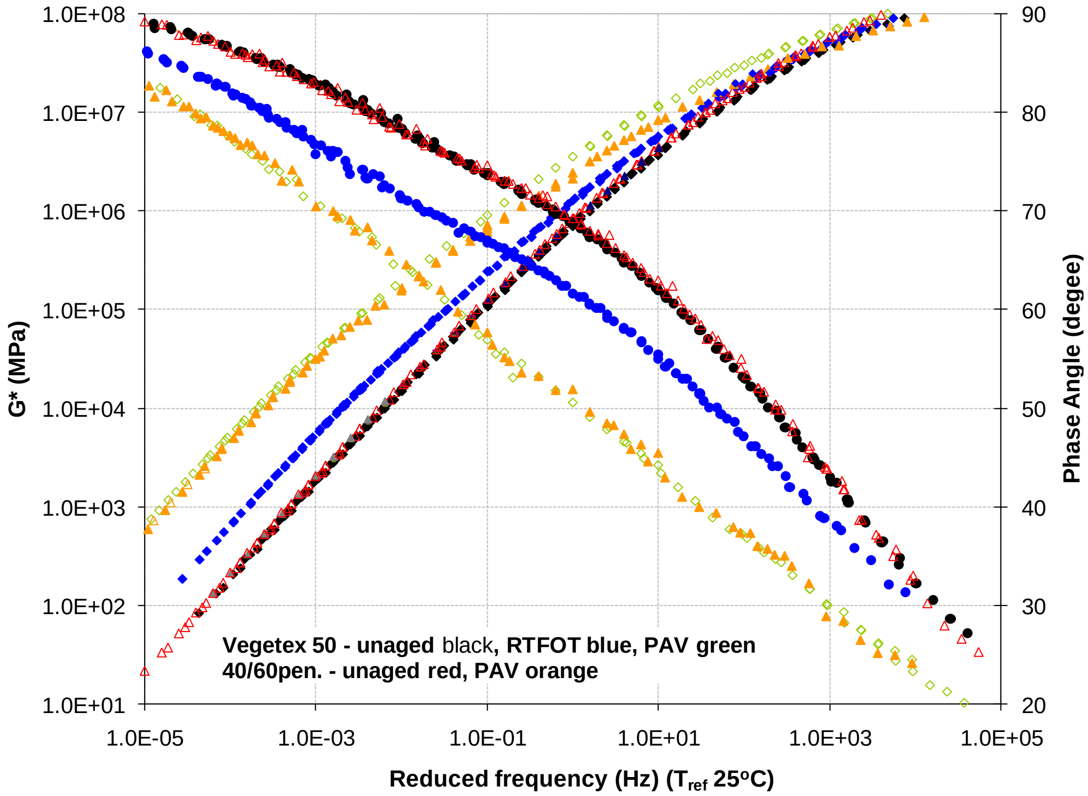

Figure 1: Complex Modulus (G*) and Phase Angle (δ) master curves at 25°C reference temperature for 40/60pen and Vegetex 50. Note; RTFOT = Rolling thin film oven aging test, and PAV = pressure aging vessel.

2. VEGETEX 50 ASPHALT MIXTURE EVALUATION

In addition to proving that the oil/bitumen blends are indistinguishable rheologically from the virgin binders, there remained the task of verifying the results using asphalt mixtures. In this section, a description of the asphalt mix composition, manufacturing protocol, and a comparison between volumetric and mechanical properties of asphalt mixtures composed of 10/20 pen + 6% oil (referred to henceforth as Vegetex 50) versus a control bitumen of 40/60 pen is presented.

A Porpherytic Andesite aggregate from Aggregate Industries (A.I.) Bardon Hill quarry was used in this investigation. The mix selected for all aspects of the experiments described and can be found in table 1. The target binder content for all mixes was 4.9%.

Table 1: Particle size distribution of the mixture used in this investigation.

Sieve Size	Target Grading (% passing)
20mm	100
14mm	95-100
10mm	72-88
6.3mm	53-67
2.0mm	27-37
1.0mm	18-28
63μm	6-10

2.1. Specimen Production

It has been reported in the literature [2] that, in addition to the effect of aggregate type and gradation on compaction, concern has often been expressed that certain methods of compaction, particularly in the laboratory, may lead to excessive aggregate degradation. Using this information laboratory roller compacted slabs were manufactured (305 × 305 × h mm), from which specimens were cored for volumetric and mechanical testing, as it has been known that the use of the laboratory roller compactor yields test specimens whose mechanical properties more closely simulate those encountered in cores removed from the field [3].

Comparison of workability, or more precisely “compactability”, of the two mixtures was achieved by monitoring the reduction in air voids during the compaction process at a fixed temperature and a pre-determined compaction effort using the gyratory compactor. The settings were 600 kPa applied vertical stress, 1.25 degrees external gyratory angle, 30 gyrations per minute, specimen diameter 100mm. Measurements were taken every gyration allowing a smooth curve to be plotted, the most significant change in air void content occurring between 0 and 200 gyrations, table 2 show that the two mix types had identical compaction profiles.

Table 2: Air Void values obtained from the gyratory compactor.

Binder	Air Void Content (%) at x Gyrations			
	10	100	200	500
40/60 pen	18.0	9.1	7.4	6.0
Vegetex 50	17.9	9.3	7.6	6.0

2.2. Evaluation of Mix Aging

Loose asphalt mixtures were subjected to short term oven aging (STOA) by placing them in a force draft oven at 160°C for 4 hours prior to compaction, in order to simulate the aging process during the mixing stage at the plant. Six specimens were manufactured per binder type using a gyratory compactor, and no change in workability was observed with STOA agreeing with the findings of earlier work [1]. In addition to workability assessment using the gyratory, indirect tensile stiffness modulus (ITSM) values were determined using a NAT (Nottingham Asphalt Tester) following STOA.

On completion of STOA and stiffness testing, the compacted samples were placed back in the oven for a further 5 days at 85°C for long term oven aging (LTOA) in order to replicate aging during the service life of the pavement. Stiffness (ITSM) measurements were again recorded. The results confirm findings of the binder thermal aging studies as both mixtures displayed increased ITSM values at similar ratios and primarily in line with expectations.

2.3. Evaluation of mix Water Sensitivity

In order to assess longer term water damage under realistic conditions, 8 thermally unaged cored specimens (4×Vegetex and 4×conventional) were immersed in water at 20°C for up to 20 weeks. At two week intervals, the samples were removed from the bath and left to condition in a temperature chamber for 4 hours prior to testing in the NAT. As the test is non-destructive, samples were re-submerged after each test. A gradual reduction in stiffness with water immersion duration is expected for all specimens, nonetheless, stiffness determinations of the Vegetex 50 were comparable to the 40/60 pen specimens.

2.4. Indirect Tensile Fatigue Test (ITFT)

To evaluate the effect of blending vegetable oil on the fatigue performance of the asphalt mixes, Indirect tensile fatigue testing was carried out in accordance with DD ABF 2002 using the NAT. A typical fatigue plot (figure 2) of initial strain against number of cycles to fatigue failure shows that the two binder types have identical performance. Hence, at any one level of stress or strain, it is expected that the virgin or oil blended mixes will perform equally well and sustain an equal number of traffic stresses (equal life).

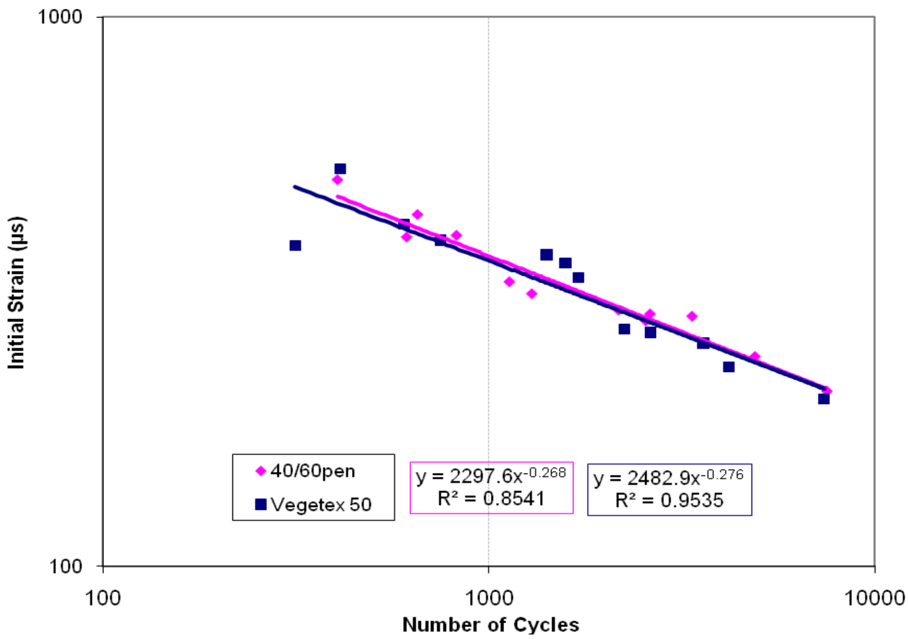

Figure 2: Fatigue performance of the 40/60 pen and the Vegetex 50 asphalt mixes.

2.5. Resistance to Permanent Deformation

The wheel tracking test was selected for evaluation of the creep or rutting behaviour of the two asphalt mixtures. Wheel tracking was carried out in accordance with BS 598-110 (1998). All 8 specimens (4 Vegetex and 4 conventional) tested passed the 7.0 mm or 5.0 mm/hr rutting criteria, as specified in The Specification for Highway Works, Vol 2, Series 900, Cl.952 (MCHW, 2008).

Further tracking was carried out at the same temperature for extended testing times (200 minutes) to investigate whether the rutting behaviour at very long loading durations will be more influenced by the binder performance or by full aggregate interlock/ maximum packing. Testing was carried out as a sequence of consecutive runs lasting 45 minutes each, until 200 minutes of tracking per sample had been achieved. It was clear that aggregate packing, and hence the gradation of the Superbase14 is what makes these mixes ideal for heavy duty basecourse layers, no difference was observed between the binders.

2.6. Recovered Binder Penetration and Softening Point

Following fatigue testing, the binder was recovered from four specimens containing 40/60 pen bitumen and four specimens containing Vegetex 50. Binder recovery was performed in accordance with BS EN 12697-1 (2005) and penetration and softening point tests were carried out in line with BS EN 1426 and BS EN 1427 respectively. The corresponding results can be found below in table 3.

Table 3: Binder properties obtained from recovery of 40/60pen and Vegetex 50

Binder	Softening Point (°C)				Penetration (dmm)			
40/60 pen	62	63	64	64	28	22	24	26
Vegetex 50	58	58	62	64	30	28	29	29

In general less aging has occurred in the blended binder as shown by lower softening point and higher penetration value.

Average softening point values for the 40/60 pen and Vegetex 50 were 63 and 61°C respectively. In terms of allowable testing errors as defined in BS EN 1427 for softening point, both binders were within the repeatability range of 1°C. Average values for penetration testing of the 40/60 pen and Vegetex binders were 25 and 29dmm respectively. Both binders were within reproducibility limits however the 40/60 pen binder fell outside the repeatability limit, making it difficult to draw conclusive results that the Vegetex binder has undergone less aging with this test alone.

2.7. DSR Analysis of Recovered Binders

In order to validate the findings obtained from penetration and softening point tests performed on the recovered binders, DSR analysis was also undertaken. Frequency sweeps were conducted within the region of linear visco-elastic (LVE) response. The DSR tests reported were performed under the following conditions: controlled strain mode of loading, test temperatures ranging from 0 to 80°C in 5°C increments, 0.01 to 10Hz test frequency. The results are presented in the form of master curves at a reference temperature of 25°C. Figures 3 and 4 compare the recovered control binder and recovered Vegetex 50 binder in terms of complex modulus (G*) and phase angle (δ).

These results were unexpected, since long term oven aging (RTFOT) experiments on the pure binders did not show any differences between the two binders. Also most of the ITSM Vegetex data was in line with the 40/60 pen results. No difference was shown in fatigue performance in figure 2 because the y axis is in terms of initial strain and this removes stiffness as a variable influencing fatigue.

It can only be concluded from this data that the recovered Vegetex in this particular exercise was actually softer than the 40/60 pen. The main possibility of how the Vegetex binder could be softer is that the procedure for blending the oil with bitumen has to be carried out quite accurately and any excess oil would have caused a big reduction in stiffness.

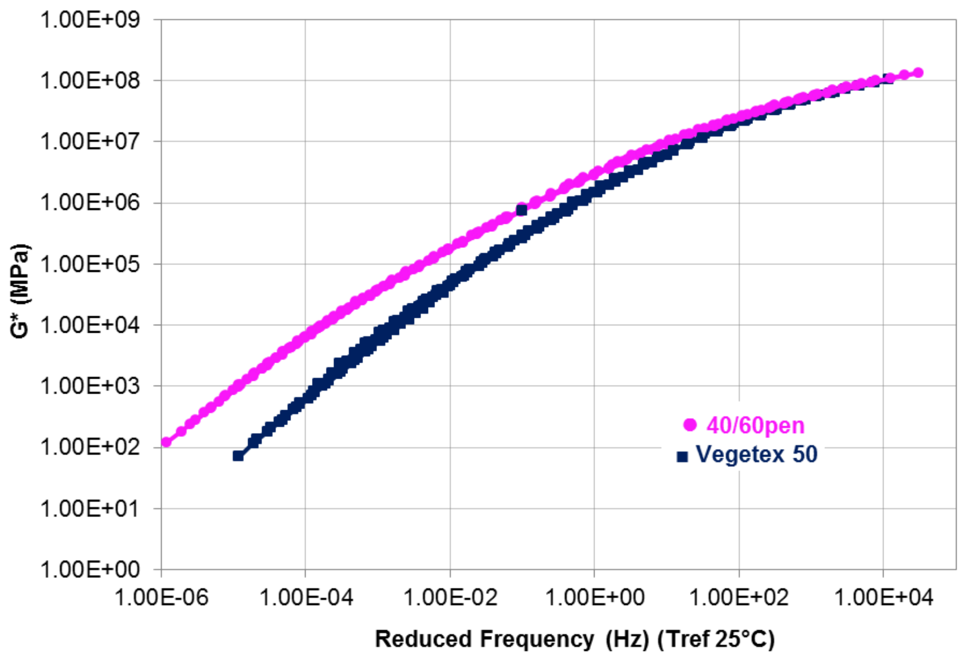

Figure 3: Complex modulus G* master curves at 25°C reference temperature for both recovered 40/60pen control mix and recovered Vegetex 50.

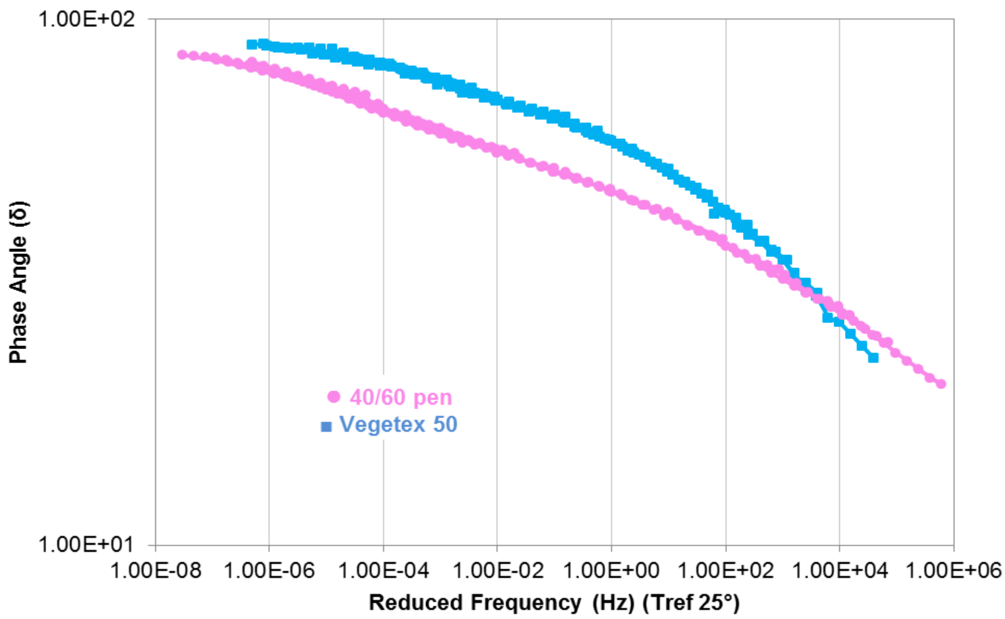

Figure 4: Phase angle (δ) master curves at 25°C reference temperature for both recovered control binder and recovered Vegetex 50.

Examining the G* mastercurves in Figure 3 shows a clear difference in the G* values between the two recovered binders. The Vegetex 50 was unambiguously "less stiff" compared to the control 40/60pen and the difference becomes magnified as the test frequency is reduced, i.e. as we approach Newtonian behaviour. This finding is fully supported the phase angle plot (Figure 4) which shows lower δ values of the 40/60pen across the majority of the frequency scale. These results also concur with the higher penetration and lower softening point values of the recovered Vegetex 50 shown in Table 3.

2.8. Utilisation of used vegetable oil

In order to verify that used vegetable oil could be used following the method and proportions described additional mixes were produced using used vegetable oil (UVO), testing of the main mechanical properties was carried out. A summary comparing all results can be found in table 4 which overall shows very similar performance across all three binder types.

Table 4: Summary and comparison of all Vegetex results

Test/Property	Values			Comments
	Control. 40/60 pen	Vegetex 50. Virgin Oil	Vegetex 50. UVO	
Indirect Tensile Stiffness Modulus (ITSM), MPa	2250	2318	3783	Minimum of 30 specimens tested
Water Sensitivity, Indirect tensile strength ratio	78.8	85.9	-	
Short term oven aging, % change in stiffness (using the NAT as described above)	45	48	44	Oven aging, developed under the SHRP-A-003A Project
Short term oven aging (STOA) and Long term oven aging (LTOA), % change in stiffness (using the NAT as described above)	62	65	49	
Indirect Tensile Fatigue Test (ITFT), DD ABF: 2003				
Number of cycles at 500µs	341	257	-	Calculated from regression equation and line of best fit through data
Microstrain at one million cycles	55	56	-	
Resistance to deformation, wheel tracking at 60°C, BS 598-110				
Final rut depth, mm after 45mins	2.1	2	2	
Final rut depth, mm after 200mins	2.9	3.2	3.3	Extended test period

2.9. Chemical Analysis

In addition to rheological properties, it was felt that an understanding of how vegetable oil interacts with penetration grade bitumens from a chemical perspective was necessary. In order to do this, samples of various bitumen grades, Vegetex binders and both virgin and used vegetable oil were analysed for their SARA fractions using Iatroscan.

The test itself, principle of operation and output is described in simple terms by Zoorob and Phillips (2006), the Iatroscan is an automatic detector that performs quantitative analysis on organic mixtures separated on thin layer chromatography (TLC) and detected by Hydrogen Flame Ionization System (FID). When a sample(s) is developed and separated on the Chromarod (thin layer quartz rod) and scanned directly into the hydrogen flame at the rated speed, organic components separated on this thin layer surface are ionized by the energy of the hydrogen flame. The ions generated are charged both negative and positive. The negative ions (-) flow to the Burner and the positive ions (+) flow to the Collector Electrode due to the electric field loaded between the FID electric poles (Burner +ve and Collector –ve). These ion currents flow between the burner and the collector proportionally to the mass of components being ionized in the hydrogen flame. The ion current is amplified by the FID circuit, and the components are quantitatively measured and recorded by the data processing unit. The results from each scan were automatically recorded in the form of a chromatogram which, in an ideal situation, consisted of 4 distinct peaks (see figure 13), each peak being representative of a particular oil fraction (i.e. Saturates, Aromatics, Resins and Asphaltenes). The Iatroscan software allowed the 4 areas under the graph, representative of the four fractions, to be easily calculated [4].

Results of the analysis can be found summarised in table 5 and clearly show that vegetable oils lie within the resin fraction. As vegetable oils lie almost entirely within the resin fraction this infers that the vegetable oil maybe acting as a peptising agent to the asphaltenes, thus keeping the asphaltenes in solution and preventing them forming a structure (which in turn translates to a transition towards a sol-gel type bitumen).

A key source of error for this experiment is that only one sample was run per binder type, results therefore serve as an indication only to aid in the explanation of the blending processes. Should additional chemical analysis be carried out, a minimum of 5 test samples should be run per binder type to assess repeatability.

Table 5: SARA analysis, a summary of various binders

Binder	SARA Fractions			
	Saturates	Aromatics	Resins	Asphaltenes
10/20 pen bitumen	3.65	45.85	31.55	18.96
40/60 pen bitumen	5.64	37.75	38.17	18.43
Vegetex 50 with virgin veg oil	4.24	39.07	36.77	19.92
Vegetex 50 with UVO	1.89	43.5	37.33	17.28
Virgin veg oil	0.01	0.46	98.74	0.80
UVO	<0.01	1.18	97.84	0.99

2.10. Summary of lab evaluation

Experimental work in this chapter has shown that blending vegetable oil with bitumen is technically easy and effective means of adjusting the viscosity of bituminous binders. Test results have shown it is possible to produce equivalent grades using the vegetable oil (virgin or used) to adjust the viscosity and there has been no evidence of any adverse effects of this on the resultant asphalt mixtures.

By blending 10/20 pen with 6% oil (virgin) to create Vegetex 50, experiments have shown that the binder is equivalent to a conventional straight run 40/60 pen in terms of rheology. Mix performance of the two binders is also indistinguishable, the Vegetex binder producing equivalent if not improved performance in the following tests: compactability, stiffness, fatigue, resistance to permanent deformation (wheel tracking), oven aging and water sensitivity. Further substitution and blending with used vegetable oil has also shown that asphalt mixtures can be produced without having detrimental effect on the performance properties. In terms of chemical analysis, results clearly show that vegetable oils lie within the resin fraction.

Although initial findings show that bitumen can be blended with vegetable oil (virgin or waste) without having a detrimental effect on the resultant asphalt mixture, laboratory mixtures are of course prepared in a controlled environment therefore it was necessary to verify and validate the initial findings through field investigations.

3. VEGETEX FIELD EVALUATION

This section of the paper presents findings of the first live road trial of a Vegetex mixture that took place on the 20th of October 2009. The materials along with a standard control mix were laid on New Road, Clifton, Bedfordshire.

3.1. Production

Mixtures for the trial were produced at Aggregate Industries Newark Express Asphalt plant. Conventional 70/100 pen bitumen was used as a control mix; whilst 40/60pen was blended with used vegetable oil (UVO) to create an equivalent Vegetex 70/100 binder (referred to henceforth as Vegetex 85).

Hardstone aggregates from Bardon Hill and Bardon Hill dust/Woodall sand were used with the binders to produce a control mixture and a Vegetex mixture equivalent to AC 10 close surf 70/100 for the trial. The compositions of the mixtures are given in table 6. Complete aggregate coating was observed after mixing.

The material was produced in 1 tonne batches, 40 tonnes of control mix and 40 tonnes of Vegetex mix were produced.

Table 6: Composition of AC10 close surf 70/100

Components	Composition (%)	
	AC10 close surf 70/100 Control	AC10 close surf Vegetex 85
4/10 mm	39.1	39.1
2/6.3 mm	27.7	27.7
0/4 mm	25.6	25.6
Reclaimed LS Filler	2.5	2.5
Binder	5.1	5.0
UVO	-	0.1

3.2. Laying and Compaction

The Vegetex and Control materials were laid at New Road, Clifton Bedfordshire on the 20^{th} October 2009. Hauling time was approximately 120 minutes. The materials were laid using a conventional paver at a thickness of approximately 40mm. The rollers and their respective operating weights to compact the mixtures were as follows:

- A Hamm HW90 roller with an operating weight of approximately 10000kg
- A Hamm HD90 with an operating weight of approximately 9100kg
- A Bomag 135 AD roller with an operating weight of approximately 3670kg

The number of roller passes was not recorded. It should be noted that due to the intense media and press presence, the laying and compaction of the Vegetex material was slowed down and therefore hindered. Weather conditions were primarily overcast and dry. The ambient temperature was around 10^{0}C.

The two materials were overlaid on an AC 20 binder course (laid the day before) with a layer of polybond 50 bond coat in between the binder course and the surface course materials. Figures 5 and 6 show the laying of the control material and the compacted end product.

Figure 5: Laying of AC10 close surf 70/100 Control

Figure 6: Compacted AC10 close surf 70/100 Control

The laying of the Vegetex and the compacted Vegetex material is shown in figures 8 and 9.

Figure 7: Laying of AC10 close surf Vegetex 85

Figure 8: Compacted AC10 close surf Vegetex 85

3.3. Trial Assessment

Compaction and delivery temperatures were recorded in accordance with BS 598:109 and BS EN 12697-13. Texture depth was carried out in accordance with BS 598: 105-5/BS EN 13036-1. Surface regularity using the 3 metre rolling straightedge was carried out in accordance with TRRL SR290/SHW CI.702.

Bulk samples of the materials were taken at site and used for compositional analysis in accordance with BS EN 12697-2 and BS EN 12697-1 binder by difference and binder recovery using Methylene Chloride. Furthermore, binders recovered from the bulk samples taken at site were tested for penetration and softening point in accordance with BS EN 1426 and BS EN 1427. Material from the bulk samples were also used to determine the maximum density in accordance with BS EN 12697-5.

Slabs (305mm × 305mm × 50mm) of each material were also prepared in the laboratory from the bulk samples. Long term aging was applied to four 100mm diameter cores that were taken from each slab. Specimens were tested for stiffness initially and were then subjected to 5 days in a force draft oven at 85°C, following which the specimens were retested to determine the percentage change in stiffness. Long term aging is used to simulate exposure in the field which is thought to represent 7 to 10 years of service.

Material from the bulk samples were also used to assess the workability with the aid of a gyratory compactor using BS EN 12697-31:2004 as a guide. Specimens were compacted at 135-155^{0}C in 100mm diameter moulds terminating at 100 gyrations. Three replicates per material were made. It should be noted that voids reported are based on calculated values obtained directly from the gyratory compactor and not from BS EN 12697 parts 6 and 8. Therefore the air voids recorded by the gyratory compactor may be an over estimate.

Four 100mm diameter cores of the control material and eight 100mm diameter cores of the Vegetex material were cored from the southbound carriageway. The cores were used to determine the bulk density in accordance with BS EN 12697-6 Procedures C (Sealed) and A (Dry), air voids in accordance BS EN 12697-8 and stiffness in accordance with EN 12697-26. Two 200mm diameter cores of the control material and four 200mm diameter cores of the Vegetex material were also taken to determine the wheel tracking rate in accordance with BS 598-110 on the small wheel tracking device at 60^{0}C.

3.4 Field Trial Results and Discussion

3.4.1. Density, voids and Stiffness

Average bulk density and air voids values for the materials are presented in table 7, values for both procedure A and C are presented, representing bulk density dry method and sealed respectively from BS EN 12697-6.

Table 7: Average Bulk density and air voids

Material	Max. Density (kg/m^3)	Avg. Bulk Density (prod A) (kg/m^3)	Avg. Air Voids (prod A) (%)	Avg. Bulk Density (prod C) (kg/m^3)	Avg. Air Voids (prod C) (%)	Avg. Stiffness (MPa)
AC 10 close surf 70/100 Control	2554	2385	6.6	2304	9.9	1807
AC 10 close surf Vegetex 85	2564	2372	7.5	2268	11.6	2981

3.4.2. Workability

Average gyratory bulk densities and air voids for each material at 10, 50 and 100 gyrations are presented in table 8. The evolution of the average air voids for each mix over the 100 gyrations is presented in figure 9.

Table 8: Average bulk density and air voids at 10, 50 and 100 gyrations

Material	Max. Density (kg/m^3)	At 10 Gyrations		At 50 Gyrations		At 100 Gyrations	
		Density (kg/m³)	Air Voids (%)	Density (kg/m³)	Air Voids (%)	Density (kg/m³)	Air Voids (%)
AC 10 close surf 70/100 Control	2554	2258	11.6	2390	6.4	2437	4.6
AC 10 close surf Vegetex 85	2564	2245	12.5	2370	7.6	2415	5.8

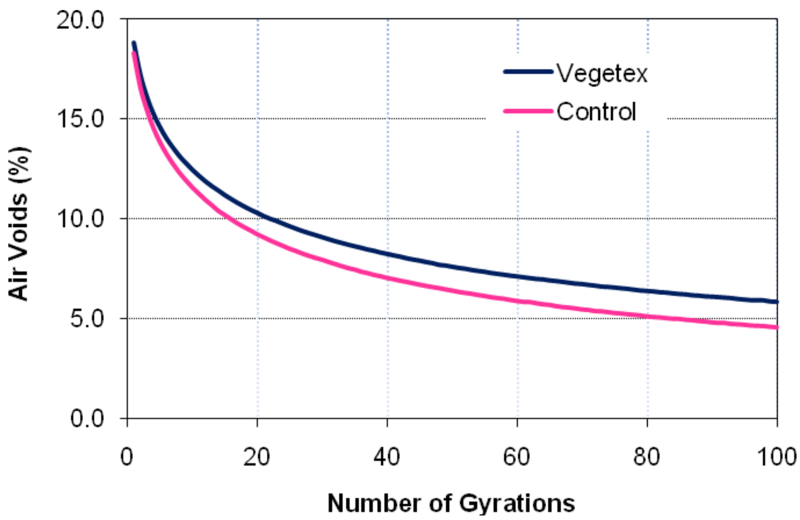

Figure 9: Evolution of average aid void content

3.4.3. Wheel Tracking

The average and individual wheel tracking values are presented in table 9.

Table 9: Individual and average wheel tracking results for the materials

Core Location (Southbound)	Material	Rut Depth (mm)	Avg. Rut (mm)	Tracking Rate (mm/hr)	Avg Rate (mm/hr)
CH 131	AC10 close surf 70/100 Control	4.2	3.8	1.9	1.7
CH 131	AC10 close surf 70/100 Control	3.4		1.4	
CH 222	AC10 close surf Vegetex 85	2.4	3.0	2	1.6
CH 222	AC10 close surf Vegetex 85	2.8		1.2	
CH 252	AC10 close surf Vegetex 85	0.9		1.2	
CH 252	AC10 close surf Vegetex 85	5.7		1.9	

3.4.4. Compositional analysis and binder recovery

The average compositional analysis found the material to be within specification. The average penetration and softening point values of the binders recovered from the mixtures were also determined and the average results are shown in table 10.

Table 10: Average penetration and softening point values from materials taken at site

Material	Penetration (dmm)	Softening Point (^{0}C)
AC10 close surf 70/100 Control	89	44.2
AC10 close surf Vegetex 85	80	48.5

3.4.5. Long Term Oven Aging

The average stiffness values before and after laboratory long term oven aging and the percentage change is presented in table 11.

Table 11: Average values for stiffness before and after aging and the Percentage change

Material	Average Stiffness (MPa)		% Change
	Before Aging	After Aging	
AC10 close surf 70/100 Control	2149	3285	53.3
AC10 close surf Vegetex 85	3314	4405	33.0

3.4.6. Texture Depth and Surface Regularity Data

Average texture depth of both materials was found to be 0.6mm with little surface irregularity.

3.5. Vegetex trial site revisited

As a follow up, a visual assessment of the site was made 6 months after laying, figures 10 and 11 show the site to be in good condition with no early signs of deterioration. The road will continued to be monitored.

Figure 10: Vegetex material, New Road approach to the village.

Figure 11: Vegetex material, New Road leaving the village.

3.6. Conclusions and Recommendations

The following conclusions can be drawn from the trial of the Vegetex material:

- It was not possible to compare on site the compaction of Vegetex material with the compaction of the control material in this report primarily due to differing speeds at which materials were laid. This was caused by the intense media presence on site which hindered the laying of the Vegetex material. However, when assessed by the gyratory compaction the Vegetex material has a similar workability to the control material.
- The specific gravity (SG) of the Vegetex was higher than that of the control, which for the same mass of compacted material and compaction effort will automatically give a lower compacted density and higher voids (table 8).
- Recovered binder properties in terms of penetration are higher than expected for both materials suggesting that both binders were at the upper limit of the 70/100 pen grade boundary when dosed into the mixer. However, results in table 10 show that the recovered penetration accompanied by a higher softening point suggests more oxidation during mixing for the Vegetex. A stiffer binder will also give rise to higher ITSM results (supporting earlier work on binder aging on its own where Vegetex possibly ages slightly more following RTFOT).
- The ITSM results after long term aging however (table 7) show that the Vegetex is more durable than the control and that any negative short term aging effects are overtaken by improvements in long term aging.
- This full scale trial has shown that Vegetex material ages significantly less (20%) than the control material. This is a positive result and will enhance the long term performance and durability of the asphalt composites.
- As expected, no difference was observed between the two mixtures in terms of texture depth and surface regularity. The binder would have minimal impact on these properties.

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