TABLE 3 - 1

EFFECT OF PVC SUBTRACTION LOOP ON CHROMATOGRAMS OF C_6-C_8 HYDROCARBONS

Mixture	Type or class of components	Actual components of mixture	Result
A	n-paraffins	Pentane, hexane, heptane octane	No peaks removed
B	Branched paraffins	2,2-dimethyl butane 2,3-dimethyl butane + hexane	No peaks removed
C	Olefins	1-hexene, 1-octene + n-octane	No peaks removed
D	Cycloolefins	Cyclohexane, cyclopentene 1,3-cyclohexadiene, cycloheptene, cyclooctatetraene	Cyclooctatetraene (only) substantially removed
E	Aromatics	Benzene, toluene, xylene + methylcyclohexane	All aromatics removed

TABLE 3 - 2

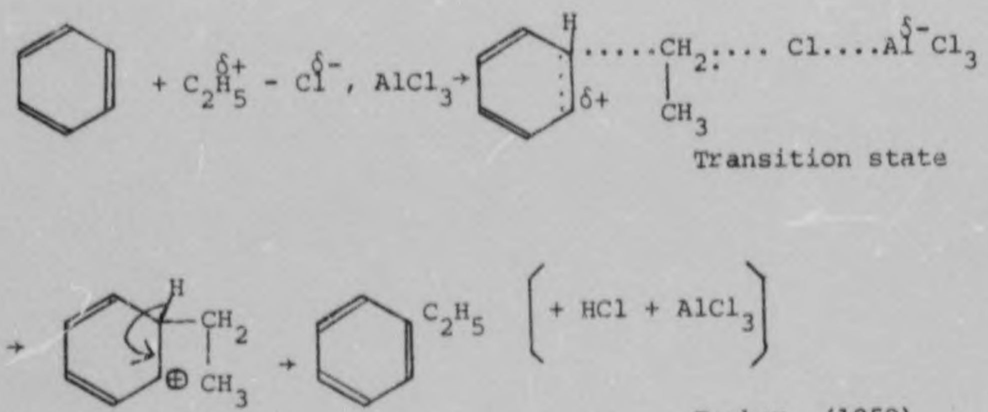
THE CHEMICAL NATURE OF BITUMINOUS BINDERS AND THEIR COMPATABILITY WITH PVC

Binder type	Broad chemical constitution	Order of aromaticity	Compatibility with PVC
Petroleum bitumen	n- and iso-paraffins, cycloparaffins, naphthenes	Lowest	Not compatible
Vertical-retort and Lurgi tars	Some paraffins, but mainly aromatic with considerable ring substitution by alkyl groups and chains, especially in the higher molecular mass compounds (Wilman, 1966)	More aromatic than bitumen, but less aromatic than coke-oven tar	More compatible than bitumen but less compatible than coke-oven tar
Coke-oven tar	Polynuclear aromatic rings with less alkyl substitution than in vertical-retort tars	Highest	Compatible.

The affinity of aromatic hydrocarbons for the PVC polymer would appear to be in effect an alkylation of the molecule by the polymer. However, on consideration of the principles it involved it is unlikely that a genuine Friedl-Crafts type of substitution in the aromatic molecule occurs. In the latter the presence of a catalyst is required to confer a positive charge to the alkyl group in the form of an addition complex. The catalyst must be a Lewis acid and is generally $AlCl_3$. The reaction has been formulated

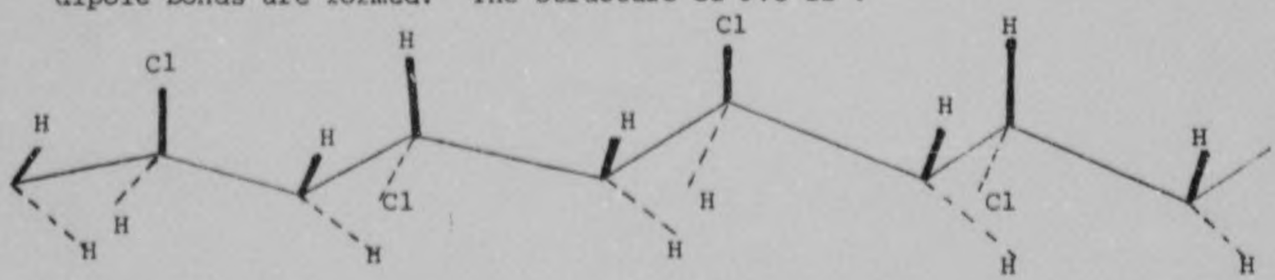
$$C_2H_5Cl + AlCl_3 \rightarrow \overset{\delta+}{C_2H_5}\ \overset{\delta-}{Cl},\ Al\,Cl_3$$

and it has been suggested that the alkylation proceeds



Tucker, (1959)

The absence of an electron-accepting complex in the PVC renders it unlikely that a similar alkylation raction occurs in PVC/tars. However, the presence of strong dipoles in the PVC and the polarisability of aromatic molecules suggests that dipole-induced dipole bonds are formed. The structure of PVC is*:



Considerable polarisation of the C-Cl bond will occur, thus $-\overset{\delta+}{C}-\overset{\delta-}{Cl}$ so that the active centre of the chain is positively polarised. Hence the affinity for PVC is probably due to the interaction of the induced dipoles in the tar molecules with the permanent C-Cl dipole in the PVC.

* Where the carbon atoms lie in the plane of the paper and bonds designated --- lie below the plane of the paper and bonds designated ▬ lie above the plane of the paper, (Natta & Corradini, 1956).

Column chromatography experiments with silica gel (Cassidy, 1957) have shown that three ring aromatics are more strongly held than one ring aromatics, the interpretation being that the greater number of aromatic rings produced the stronger induced dipole. Assuming that the strong dipoles in the PVC have a similar effect, it woul be expected that the higher ring systems would be absorbed preferentially and in tars the PVC may be associated more strongly with the higher molecular mass fractions and with condensed rather than linear ring systems.

From this study the lesser affinity that PVC has for binders comprising branched molecules and alkyl-substituted aromatics may be explained. Apart from steric hinderance factors, branched molecules will have a weaker interaction due to the weaker dipole arising from the tendency of alkyl groups to donate electrons to the secondary or tertiary carbon atoms.

3.1.2 Effect of PVC addition on the properties of tar

The special properties of PVC/tars were investigated using blends prepared from 50 - 55°C Evt road tars and fluxing oils received from three local suppliers: The Pretoria works of the South African Iron and Steel Corporation, Dundee Road Tar Products (Pty) Ltd., and Wankie Colliery Ltd. Blends containing 0;1; 1,5; 2,0 and 2,5 per cent PVC were prepared.

Viscosity

The increase in viscosity brought about by adding PVC to tar is virtually proportional to the amount of PVC added, as shown in Figure 3 - 2. The fact that one per cent of PVC causes an increase of approximately 6°C Evt, affords a means of estimating the effective PVC content of a blend, provided the original Evt of the tar is known.

Temperature susceptibility of viscosity

The viscosity of the binders was measured over the range of 15 - 45°C using the sliding plate microviscometer (Labout and Van Oort, 1956). The Temperature Susceptibility Index was calculated (Deadman, 1956) which makes allowance for differences in Evt and incorporates the logarithimic temperature coefficient which is the slope of the viscosity/temperature plot ;

$$n = \frac{\log \eta_1 \quad \log \eta_2}{\log T_2 - \log T_1}$$

(η = viscosity (poises) and T = temperature °F)

The Temperature Susceptibility Index (T.S.I.) $= \frac{n + 3}{40 + Evt} \times 100$

and values for the various PVC/tars and typical bitumen values are given in Table 3 - 3.

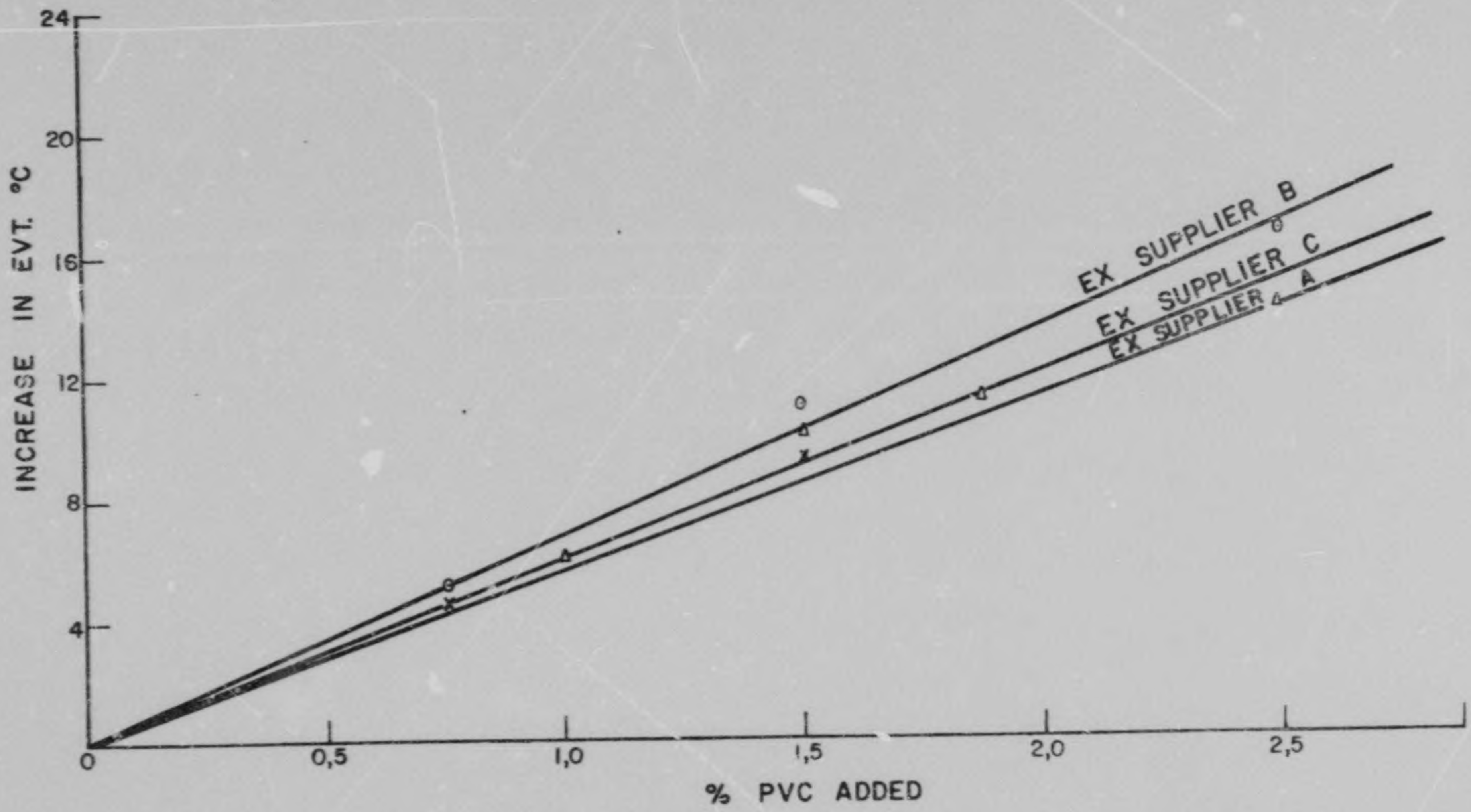


FIGURE 3-2

EFFECT OF ADDITION OF PVC UPON THE EVT OF COKE-OVEN TARS

TABLE 3 - 3

THE TEMPERATURE SUSCEPTIBILITY INDEX OF

PVC MODIFIED TARS AND TYPICAL VALUES FOR BITUMENS

Binder	PVC content, percentage by mass			
	0	1	1,5	2,0
Tar A	13,9	13,4	13,2	11,6
Tar B	15,5	15,0	13,9	13,8
Tar C	15,3	14,9	13,6	12,9
150/200 Pen.bitumen	11 - 13 (typical range)			

Brittleness

A further effect of this change in the rheological nature of tar is an extension of the temperature range between the brittle temperature and the Evt. This was ascertained from investigations in which 1,5 per cent of PVC was added to each binder and the Evt and brittle temperatures* of the original and modified binders were determined. These results are given in Table 3 - 4 and show that although addition of PVC to tar causes an increase in Evt, the brittle temperature does not alter appreciably (on addition of 1,5 per cent of PVC)

TABLE 3 - 4

THE EFFECT OF PVC ADDITION ON THE BRITTLE TEMPERATURE OF TAR

Binder	Evt °C	Fraass brittle temperature °C	Evt - brittle temperature °C
Tar A	52,3	-7,0	59,3
Tar A + 1,5 per cent PVC	60,4	-5,0	65,4
Tar B	55,2	-5,0	60,2
Tar B + 1,5 per cent PVC	64,1	-4,5	68,6
Tar C	50,9	-11,0	61,9
Tar C + 1,5 per cent PVC	60,1	-8,0	68,1

* The automated version of the Fraass test as described in Part 2, Chapter 4 and Appendix G was used in these investigations.

Stiffness

Stiffness functions of various surface treatment binders including PVC/tar have been determined by Daines (1972) at 10,0 and -10°C using a microelastometer described by Labout (1958). These values are shown in Figure 3-3. Of these unweathered binders, which all had similar equiviscous temperatures (45-47,5°C), the bitumen had a lower stiffness than any of the other binders. However, the PVC/tars had a lower stiffness than the unmodified tar and this was most pronounced in the case of the tar containing the highest PVC content.

Adhesion/cohesion

It was noted that when a stone chipping was thrown forcefully onto a freshly sprayed film of the binder, during a PVC/tar surface treatment operation, it was gripped immediately whereas under similar conditions with unmodified tar or bitumen the stone rolled or bounced before being held by the binder film. It was noticable, when driving over a newly constructed PVC/tar surface treatment , that the drumming of loose chippings on the underside of the vehicle was almost eliminated.

The results of laboratory adhesion tests show that these phenomena are not brought about by enhanced interfacial bonding between the tar and the stone. In the absence of any universally accepted adhesion test, the detachment method developed by Karius and Dalton (1964) was used to compare the wetting properties of unmodified and PVC modified tars. (It should be noted that this test was developed to compare the efficiency of adhesion agents for particular binder-stone combinations and not as a general adhesion test.) The unmodified 50 - 55°C Evt tars and unmodified and PVC modified tars from local suppliers were subjected to the test* and the results are presented in Figure 3 - 4. No significant reduction in "detachment"resulted through the addition of 1,5 per cent of PVC to any of the binders. This contrasted with results given by a blend of tar A containing 8 per cent of a fine

---

* A film of binder, 0,9 mm thick is placed in a Petri dish and pre-washed dry-stone chippings (7,9 - 6,7 mm) are lightly pressed into the film. After equilibrating at 20°C for 16 hours excess chips are removed and the dishes placed in water. The stones detached are determined daily by turning the dishes upside down and applying light finger pressure to each stone. Each binder-stone combination is tested in duplicate and the mass of stone detached is expressed as a percentage.

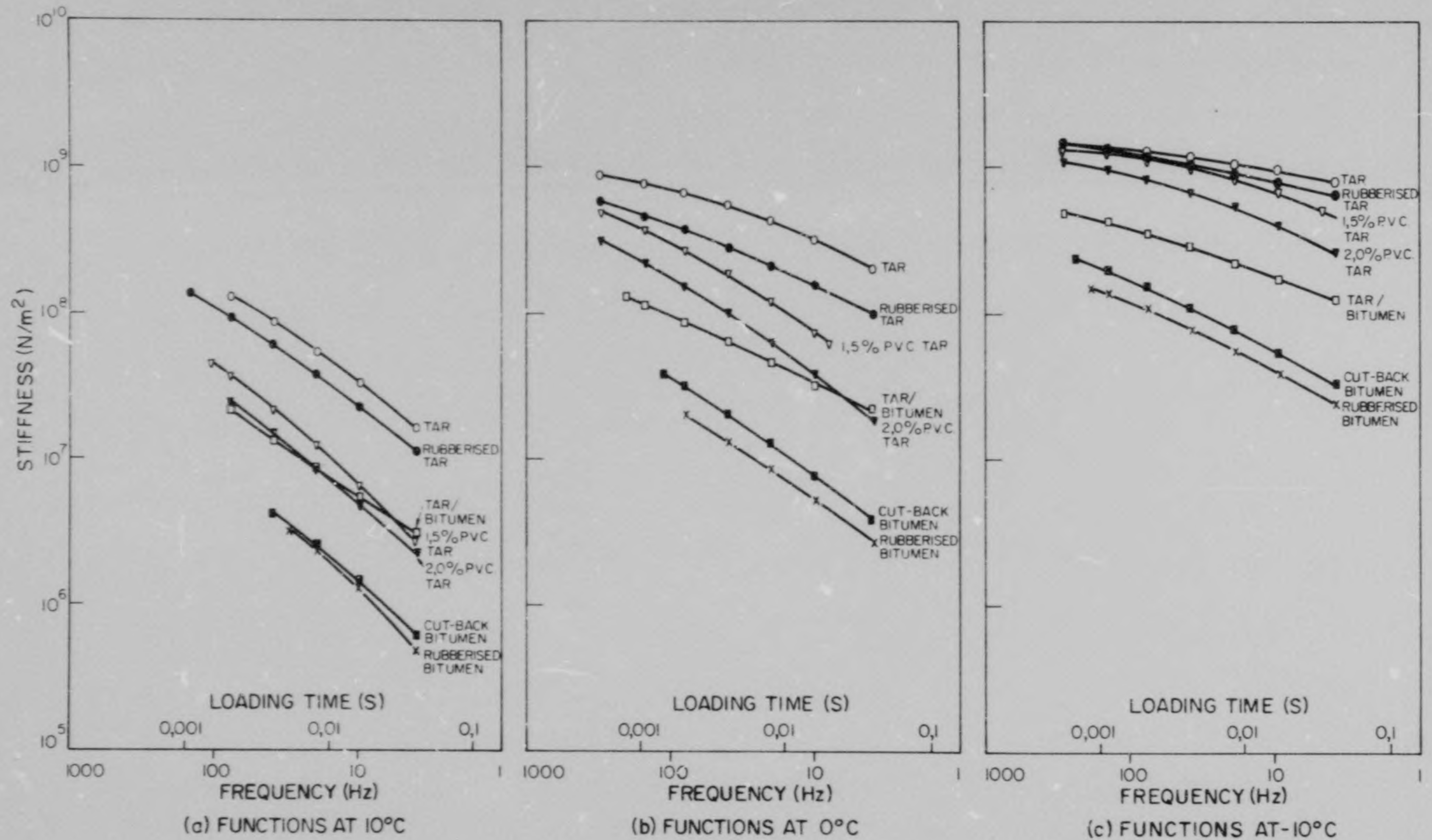


FIGURE 3-3

STIFFNESS FUNCTIONS OF SURFACE DRESSING BINDERS HAVING SIMILAR EQUIVISCOUS TEMPERATURES (46° ± 1,5°C) (From Daines 1972)

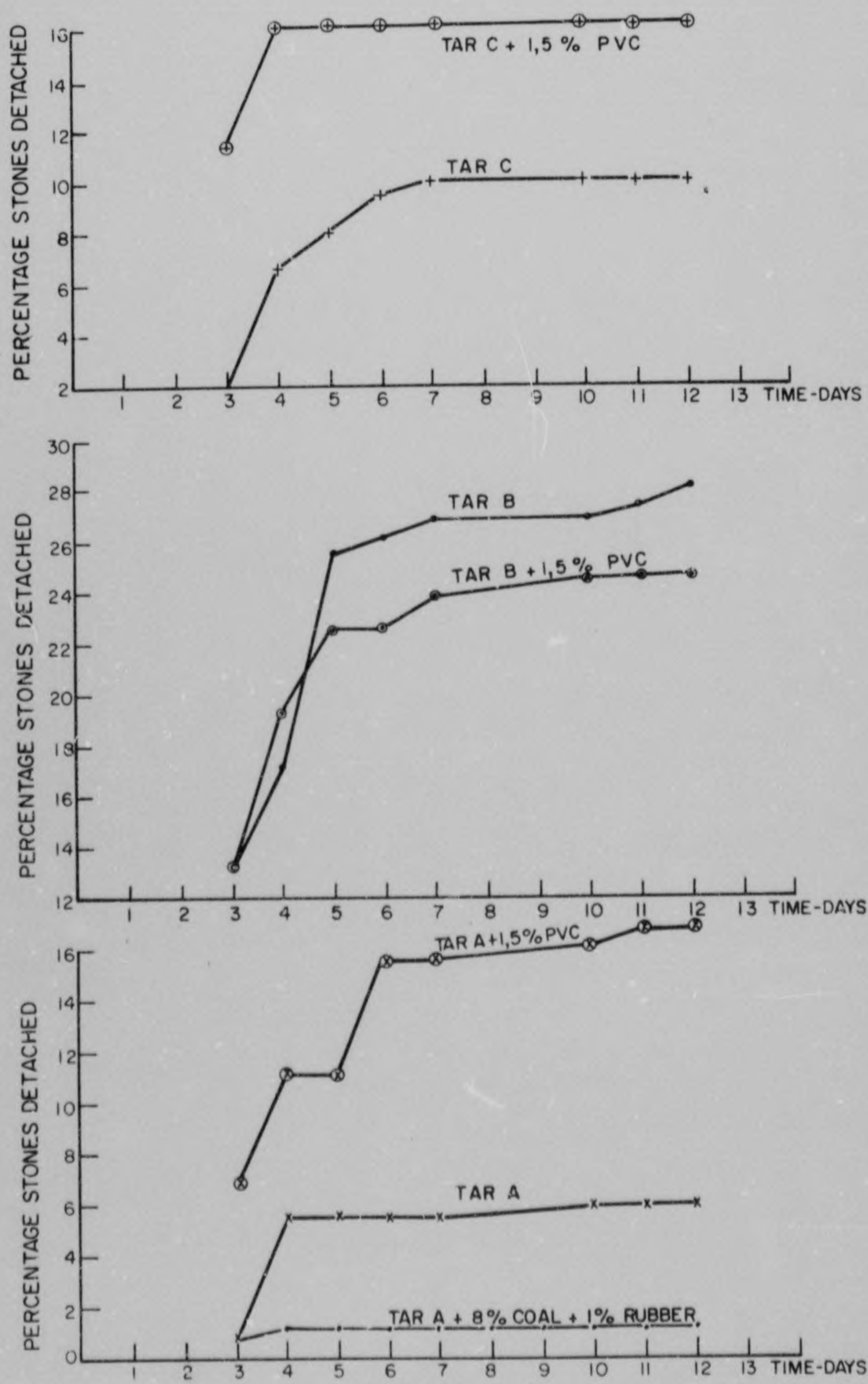


FIGURE 3-4

DETACHMENT TEST RESULTS GIVEN BY LOCAL UNMODIFIED AND PVC MODIFIED COKE-OVEN TARS.

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coal dispersion and 1 per cent acrylonitrile butadiene rubber used by NITRR in an earlier road experiment.

It has been established that the improved "grip" of the binder demonstrated in practice is due to its outstanding elastic and cohesive properties.

Elasticity

PVC/tars are very elastic. In order to measure their elasticity the sliding plate microviscometer was modified according to the procedure suggested by Szatowski (1967) in which recovery, on removal of the applied load, is expressed as a percentage of the film thickness*. Values given by PVC/tars containing various amounts of PVC are given in Table 3 - 5.

TABLE 3 - 5

ELASTIC RECOVERY (PERCENTAGE OF FILM THICKNESS) OF PVC/TAR BLENDS PREPARED FROM TAR MATERIALS SUPPLIED BY SOUTH AFRICAN MANUFACTURERS

PVC content per cent by mass (nominal)	Tar A	Tar B	Tar C
0	0	9	11
0,75	81	106	102
1,5	168	246	163
2,5	225	287	235

This property has been said to be responsible for the very low rate of stone loss which is a feature of the initial behaviour of PVC/tar surface treatments. It had been claimed (Kuhnel and Wilman, 1969) that at relatively low temperatures, chippings partly dislodged from the surface can be returned to their original position by the elastic recovery of the binder. However, a more useful way of studying these properties is by the ductility-tenacity test.

* The precision of the method was investigated by the author and it was found that if the test temperature was such that the viscosity was in the range $5 \times 10^5 - 2 \times 10^6$ Ns/m², ninety five per cent of the results fell within $\pm$ 17 of the mean value.

3.1.3 Ductility-tenacity of PVC/tar

The property of PVC/tars which clearly distinguishes it from unmodified tars and bitumens, is the formation of long strings of the binder when a chipping is pulled from a freshly constructed surface treatment. These "threads" are considerably longer than in comparable situations where unmodified tars or bitumens have been used. Furthermore, the PVC/tar threads are relatively thick and the thread diameter decreases only slightly as the chipping is pulled further from the film. The maintenance of a steady force is required for complete separation of the stone from the surface.

In Europe workers have quantified these forces and displacements by adapting a ductility-tenacity test (Distigoudron, 1967) previously used by the Goodyear Tyre and Rubber Company, later developed by the Centre de Recherche Routiers, and finally by the Institute du Génie Civil de l'Université de Liège. In this test a steel ball, half immersed in the binder, is withdrawn at a constant rate. The load developed during the withdrawal is measured and the results are expressed as the ratio of W, the work done in extending the thread over 1 metre, to L, the initial force required to overcome viscous resistance.

An apparatus was developed (Edler and Jamieson, 1973) by modifying the standard ductilometer, used for standard bitumen ductility tests, to enable the ductility tenacity of PVC/tars used in these investigations to be measured.

3.1.3.1 Design of the modified ductilometer apparatus

The major modifications to the apparatus were as follows.

Firstly, the gearbox was altered to give strain rates of 50 and 500 mm/minute instead of 10 and 50 mm/minute in the existing system. The higher strain rate is, of course, standard for testing bitumen.

Secondly, the studs to which the "stationary" half of the mould is attached, were placed on a light perspex trolley instead of being fixed to the end of the ductilometer bath as in the standard apparatus.

Additions required for measuring and recording the forces developed on stretching were:

1 A sensitive proving ring (fitted with four 600 ohm strain gauges) connected by a nylon coated steel wire to the trolley via a free-running pulley. This system is illustrated in Figure 3 - 5.

2 An electronic recorder to record the forces measured by the proving ring. The recorder was fitted to a console from which the recorder, ductilometer motor, pump and bath heating systems could be controlled (Atkins, 1969). This is illustrated in the general view Figure 3 - 6.

These additions and modifications were such that they did not prohibit the use of the apparatus for standard ductility-measurements.

3.1.3.2. Theory of operation

A typical force versus elongation curve for a road tar or bitumen is shown in Figure 3 - 7 (a) and a typical curve for a PVC/tar (containing 1,5 per cent PVC) is shown in Figure 3 - 7 (b).

In the case of the unmodified tar or bitumens, the force required to stretch the sample, or the force developed during stretching, rises rapidly to a peak value then falls to zero as the binder-thread diameter diminishes. The initial peak value L, is proportional to the viscosity of the binder.

If PVC/tar is tested in the same manner, after the initial peak force is reached the elasticity of the binder causes a further resistance to stretching, the force value does not drop to zero and a second peak or hump is given on the recorder.

The shaded areas in Figures 3 - 7 (a) and 3 - 7 (b) correspond to W, the work done in stretching the samples through 1000 mm. W is also dependent on the viscosity of the binder but the ratio of W to L has been found to be constant (Wilman, 1970) over a limited temperature range. The $^{W}/_{L}$ ratio can be used as a measure of the cohesive strength or tenacity of a binder which is independent of viscosity over a given viscosity range.

3.1.3.3 Test procedure

In accordance with methods developed in Europe an elongation rate of 500 mm/min is most suitable. The test temperature must be such that the initial peak load developed by two briquettes is 10 N $\pm$ 2,5 N.(This is equivalent to a viscosity of 1,0 - 1,5 x 10^5 Ns/m^2.)

Sample briquettes are prepared in the manner normal for standard ductility measurements, (Institute of Petroleum, 1968). The instrument

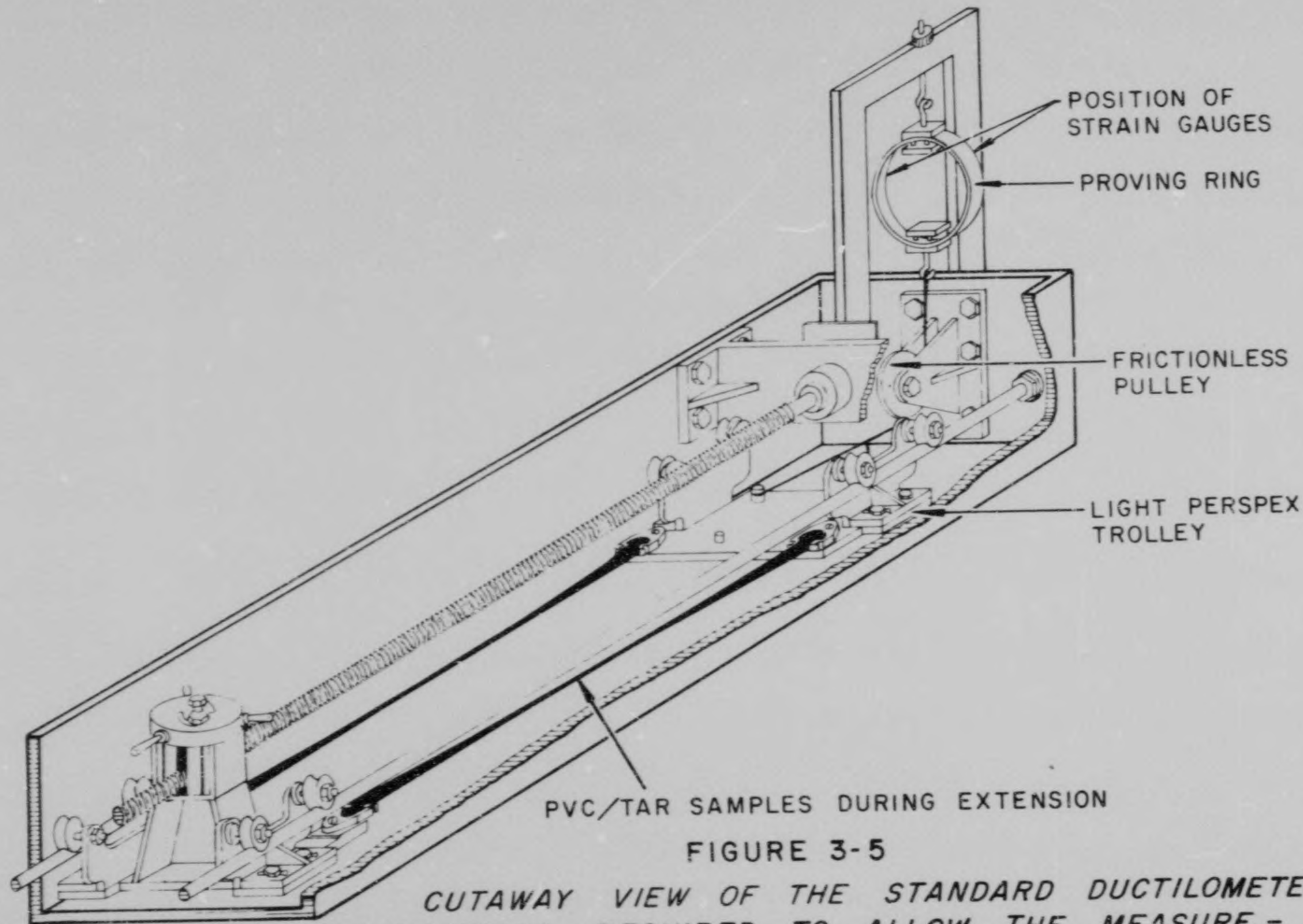

FIGURE 3-5

CUTAWAY VIEW OF THE STANDARD DUCTILOMETER SHOWING ADDITIONS AND MODIFICATIONS REQUIRED TO ALLOW THE MEASUREMENT OF THE FORCES DEVELOPED DURING THE EXTENSION OF PVC/TAR SAMPLES

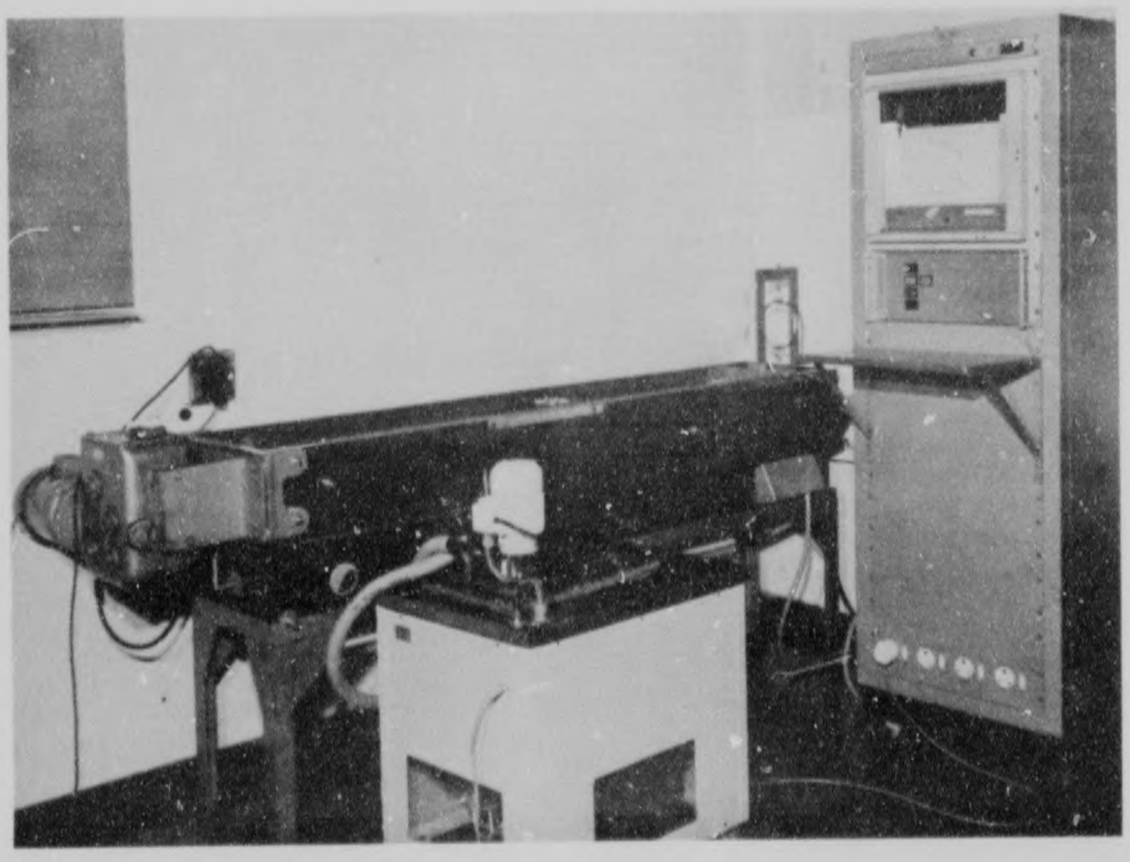

FIGURE 3 - 6: General view of the modified ductilometer and ancillary equipment.

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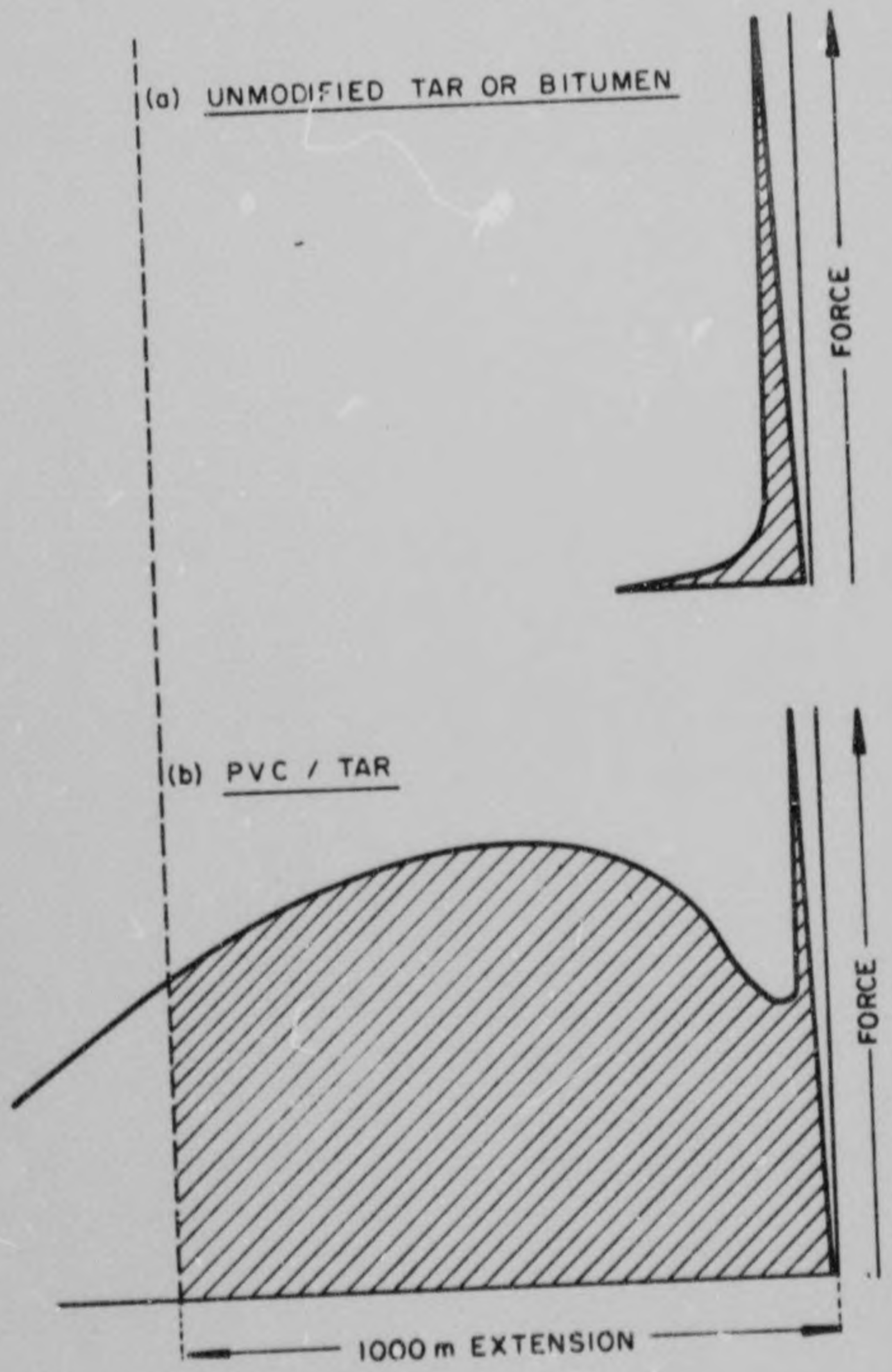

FIGURE 3-7

FORCE-EXTENSION CURVES FOR (a) UNMODIFIED TAR OR BITUMEN AND (b) PVC / TAR used had four sets of studs, i.e. each set consisting of one stud on the draw-plate, which is driven by the threaded drive bar, and a corresponding stud on the perspex trolley. Two briquettes per test are placed in the two central positions. When inserting the briquette moulds, the draw-plate is placed so that no stress is exerted on the briquettes. The draw plate is then locked onto the drive-bar and the side pieces are removed from the mould. The recorder is then zeroed, the drive activated, the motor started and the samples stretched to the limit of the apparatus (1,2 m) or until zero force is indicated on the recorder.

The $^{W}/_{L}$ ratio was determined by feeding the coordinates of the curve onto punch cards via a pen plotter, and the initial peak load, work done and $^{W}/_{L}$ ratio were determined via a computer program. (The load scale was calibrated by hanging known masses from the wire attached to the proving ring.)

Measurements of elastic recovery and ductility-tenacity show that there is not necessarily any correlation between these properties. Values given by locally available synthetic-rubber lattices dispersed in tar and a PVC/tar are given in Table 3 - 6.

TABLE 3 - 6

ELASTICITY AND DUCTILITY-TENACITY, $^{W}/_{L}$ RATIO, OF POLYMER MODIFIED TARS

Binder*	Elastic recovery Percentage of film thickness	Ductility-tenacity $^{W}/_{L}$ (mm)
Coke-oven tar + 1,5 per cent PVC	210	741
Coke-oven tar + 1,5 per cent Revertex A260	107	163
Coke-oven tar + 1,5 per cent Revinex I640	263	213
Coke-oven tar + 1,5 per cent Savinex 37H40	113	195
Lurgi tar + 1,5 per cent Savinex 37H40	150	190

* Although the same coke-oven tar (60°C Evt) was used in the preparation of all the blends, because of the different compatibilities of the various polymers the final Evt of the blends was not the same, viz;

PVC/tar = 69,0°C Evt, Revinex/tar = 64,6°C Evt, Revertex/tar = 63,0°C Evt

The ductility-tenacity test may be considered to be more appropriate than the elastic recovery test for evaluating polymer/tars used as surface treatment binders. The rate of strain in the ductility-tenacity test is relatively high compared with that in the elastic recovery method which, as has been mentioned, is a measure of strain recovery on removal of a static load. Acrylonitrile butadiene-modified tars have been used with success in various countries in the preparation of surface courses in parking areas where vehicle speeds are low and loads are mainly static. (Tar binders are often used for such mixes (McGovern, 1976) because tar is less soluble than bitumen in fuel and hydraulic oils which are frequently spilled in these areas.). PVC/tars have also been used for these mixes (Holden and Williams, 1975). The acrylonitrile-butadiene modified tars would however, be less suitable for use in surface treatments and a sample of a commercially prepared blend had a less satisfactory ductility-tenacity $^W/L$ ratio than PVC/tars which contained a lower nett polymer content. Results determined from the tars containing 3 per cent acrylonitrile butadiene and 1,5, 2,0 and 2,5 per cent PVC are given in Table 3 - 7.

TABLE 3 - 7

ELASTIC RECOVERY AND DUCTILITY-TENACITY VALUES GIVEN BY TAR CONTAINING 3 PER CENT OF ACRYLONITRILE BUTADIENE AND LOCAL COKE-OVEN TARS CONTAINING VARIOUS AMOUNTS OF PVC

Binder	Elastic recovery Percentage of film thickness	Ductility-tenacity $^W/_L$ (mm)
Tar + 3 per cent acrylonitrile butadiene rubber	398	953
Tar + 1,5 per cent PVC	210	741
Tar + 2,0 per cent PVC	273	1 048
Tar + 2,5 per cent PVC	304	1 512

Although the commerical rubber/tar blend had an equivalent elastic recovery, its ductility-tenacity was inferior to that of a tar containing 2 per cent PVC.

However, ductility-tenacity tests on very high PVC-content PVC/tars show that these binders are unsuitable for use in surface treatments. Two series of PVC/tar blends were prepared each having PVC-contents ranging from 1 - 5 per cent; in one case all the blends had Evt's in the 50 - 55°C Evt range and in the other the Evt's were in the 60 - 65°C Evt range. As shown in Figure 3 - 8 (a), with blends containing above 3 per cent of PVC the thread broke during the extension in the ductilometer and this result is typical of the brittle behaviour of very elastic material (see Briggs' work described in Part 2, Chapter 4). The results of elastic recovery tests are shown in Figure 3 - 8 (b) and hence for tars containing such high PVC-contents, the static method was the only means of gauging the elastic properties.

The test was useful in showing that large differences in the elastic-cohesive properties of commercial PVC/tars exist even though the actual PVC-contents are similar.

The $^{W}/L$ values are proportional to the PVC-content in laboratory blends using one tar-and -PVC type. In field work, however, ductility tenacity test results could not be exactly related to the actual PVC-content. Apart from some difficulty in evaluating whether the PVC is fully dispersed in the tar or whether some degradation has occurred, the slight variations in the types of heavier molecules present in the coke-oven tar may affect the compatibility between the PVC and the tar. Values given by various blends used in road trials are given in Table 3 - 8 which also indicates that this factor is likely to be important in terms of the performance of these blends.

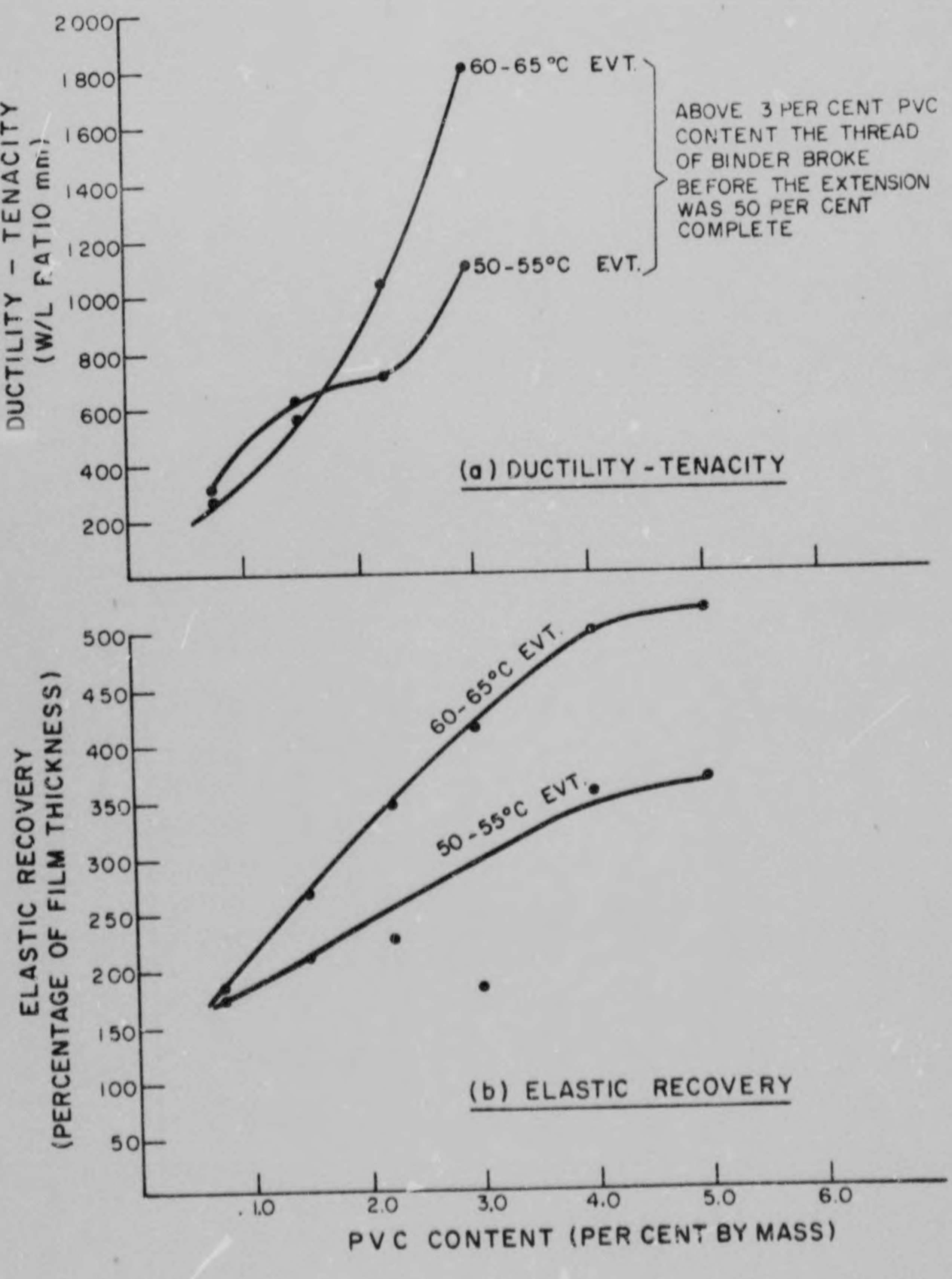

FIGURE 3-8

DUCTILITY - TENACITY AND ELASTIC - RECOVERY OF 50 - 55°C AND 60 - 65°C EVT BLENDS CONTAINING VARIOUS AMOUNTS OF PVC.

TABLE 3 - 8

$^W/_L$ RATIOS AND PERFORMANCE OF PVC/TARS USED IN FIELD TRIALS AND ROAD EXPERIMENTS IN SOUTHERN AFRICA

Location	PVC content per cent by mass	$^W/_L$ (mm)	Performance
Johannesburg contract	1,5	500-1000	Satisfactory after 6 years
Orkney-Bothaville:			
(Supplier B)	1,5	550- 700	Satisfactory after 5 years
1968 Lynnwood Road:			
(Supplier B)	1,5	380	Satisfactory after 5 years
1970 Lynnwood Road:			
(Supplier A)	1,5	380	Satisfactory after 7 years
Orkney-Bothaville:			
(Supplier C)	1,5	380	Satisfactory after 5 years
(Supplier A)	1,0-1,3	300- 410	Satisfactory after 5 years
Sinoia	1,1	310	Satisfactory after 4 years
Eldoraigne	1,0	280	Unsatisfactory
1968 Lynnwood Road:			
(Supplier A)	1,5	280	Unsatisfactory
(Supplier C)	1,5	280	Unsatisfactory
Delmas	1,0	215	Unsatisfactory
Greytown	1,0	205	Unsatisfactory
De Aar	1,4	160	Unsatisfactory

* Latest available results.

3.1.4 Manufacture and storage of PVC/tar

3.1.4.1 Manufacturing methods

It has been mentioned (Ansart, 1967) that the most suitable method of incorporating PVC into tar depends upon the characteristics of the materials being used and that no particular procedure has been universally accepted. Basically two methods appear possible ; direct addition of the PVC to the tar in a manner similar to that suggested by Rofidal, (1967), in which the viscosity of the tar is first adjusted so that subsequent additions of the desired quantity of PVC brings the Evt to the required level, or indirectly by preliminary preparation of a PVC/tar-flux-oil blend which is then added to a calculated quantity of pitch of suitable viscosity.

The bulk of PVC/tar used in South Africa is prepared by the direct addition of PVC to road tar. This has the advantage of easier control; the increase in Evt on addition of a given mass of PVC is known so that the Evt of the base tar may be selected bearing in mind the expected increase and the required Evt of the PVC/tar.

However, it may be that the indirect procedure results in an easier or more efficient dispersion of the PVC particles permitting them to absorb tar-oil constituents more readily from the low-viscosity flux-oil. In a laboratory investigation it was found that tars from three different sources all had slightly superior elastic properties when PVC/tar blends were prepared in the laboratory by the indirect as opposed to the direct method. These results are given in Table 3 - 9.

TABLE 3 - 9

EFFECT OF MIXING PROCEDURE ON THE ELASTIC RECOVERY OF PVC/TAR

PVC per cent	Tar A		Tar B		Tar C	
	Direct	Indirect	Direct	Indirect	Direct	Indirect
0,75	175	193	153	231	132	136
1,5	249	281	219	326	197	234

With the assistance of local tar manufacturers a pilot plant was set-up to digest the PVC powder in the flux-oil. A flow diagram of the system is given in Figure 3 - 9. The oil was circulated and the PVC added at a point up-stream of the pump so that the shearing action of the latter assisted in the dispersion of the PVC. Care was necessary in adding the PVC to prevent the formation of large lumps which tended to block the pipes and halt the circulation of the oil. The cylindrical tank was heated by means of a steam coil and it was found that a temperature of about 100°C was the most suitable. This system has been used to prepare PVC/tars for field trials and road experiments. One manufacturer has installed a larger version of this system for the full-scale production of PVC/tar.

In France, great emphasis is placed on the type of flux-oil used. Crystalline matter is removed and it is specified that no further material should precipitate from the oil at 20°C. (Jamieson, 1973).

3.1.4.2 Determination of the PVC content

Laboratory methods for establishing the PVC-content of PVC/tar blends, are based on the estimation of the chlorine content by chemical means. For practical purposes a rapid method is essential.

Kuhnel and Wilman, (1969) have described an oxygen flask method. The method developed for this work is based on a BS standard method for the determination of the chlorine in coal in which the sample is burned in a horizontal tube furnace. Details are given in Appendix H.

3.1.4.3 Effect of PVC addition on the production of low-volatile blends

It has been mentioned that the addition of PVC to tar causes an increase in the Evt. Thus a PVC/tar made up from a given pitch and flux-oil contains a greater quantity of flux-oil than an unmodified tar prepared to the same Evt using the same starting materials. To demonstrate this point the fluxing investigation described in Part 2 Chapter 3 was repeated and five PVC-modified tars were prepared from the same five pitches (40, 50, 60, 70 and 80°C nominal softening point; ring and ball) and the same heavy tar-flux-oil used in the preparation of the unmodified tars. Five PVC/tar blends all had a final PVC content of 1,5 per cent and the Evt of these blends was nominally the same as that of the unmodified tars. (In fact the unmodified tars had Evt's ranging from 52,5 - 54,5°C and the PVC/tars ranged in Evt from 51,5 - 54,4°C). The effect of the PVC addition upon the amount of flux-oil required in the preparation of each blend and the resultant volatile-oil content is shown

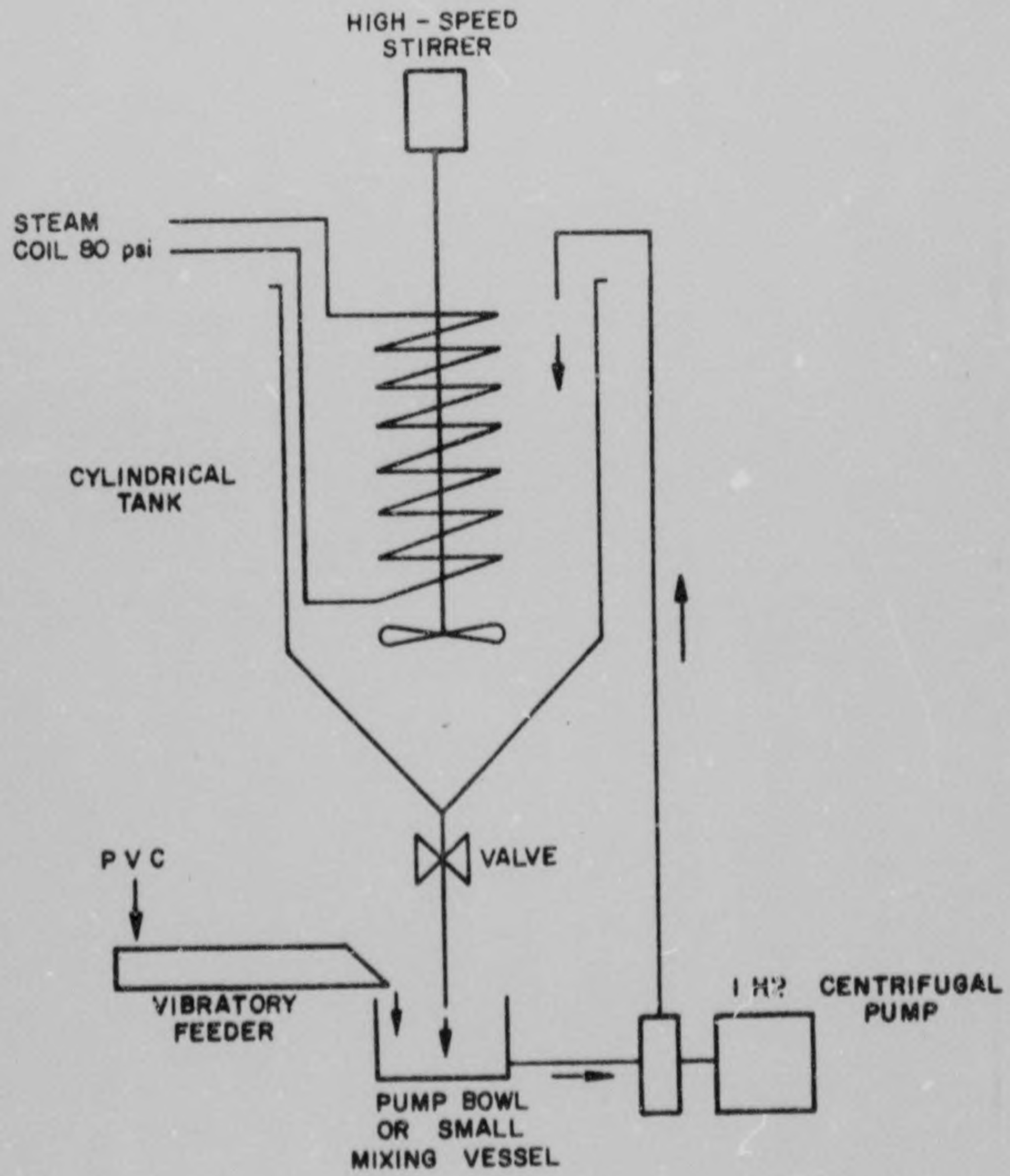

FIGURE 3-9

EQUIPMENT USED FOR BLENDING PVC / TARS USED IN FIELD TRIALS in Figure 3 - 10. Similarly the effect of the change in composition upon the softening point of the distillation residue is shown in Figure 3 - 11.

It has been shown (Figure 2 - 26) that the heavy-tar-flux-oil mainly consisted of plasticising oils and hence the use of the additional amounts of HTFO in preparing PVC/tar blends results in a lowering of the volatile-oil content of the blend and a decrease in the softening point of the distillation test residue. From Figures 3 - 10 and 3 - 11 it can be seen that the addition of 1,5 per cent PVC had the same effect as increasing the softening point of the pitch component by 10°C. Nevertheless, whereas these distillation criteria are measures of the durability of tars, by inclusion of PVC it is possible to improve the inherent durability of the tar, provided heavy oils are used in blending

3.1.4.4 Hot storage of PVC/tar

Because road maintenance procedures are prone to delays, due to weather and breakdowns, PVC/tars should be able to withstand storage at spraying temperatures for reasonable periods of time.

Tests conducted on tars modified by various other synthetic polymers (Jamieson, 1968) showed that the polymers tended to degrade when these binders were stored at 110°C for periods longer than eight hours. The effect of storage for periods of up to 96 hours on the ductility, elasticity, and brittleness of tar modified by various synthetic rubbers is shown in Table 3 - 10.

The procedures used in the laboratory investigations of the hot storage properties of polymer/tars and the effect of degradation of the polymer on the physical properties of the binders are described in Appendix I. The investigations showed that some of the properties of tars containing degraded polymers were inferior to those of unmodified control samples.

Hot storage tests were conducted on blends prepared using products obtained from local suppliers, as described in Part 3, Chapter 1.2. Blends containing 0,75 and 1,5 per cent PVC were stored for periods of up to 96 hours and the condition of the polymer was monitored by measuring the elastic recovery of the binder. The elastic recoveries of these binders after 24 hours and 96 hours storage are given in Table 3 - 11.

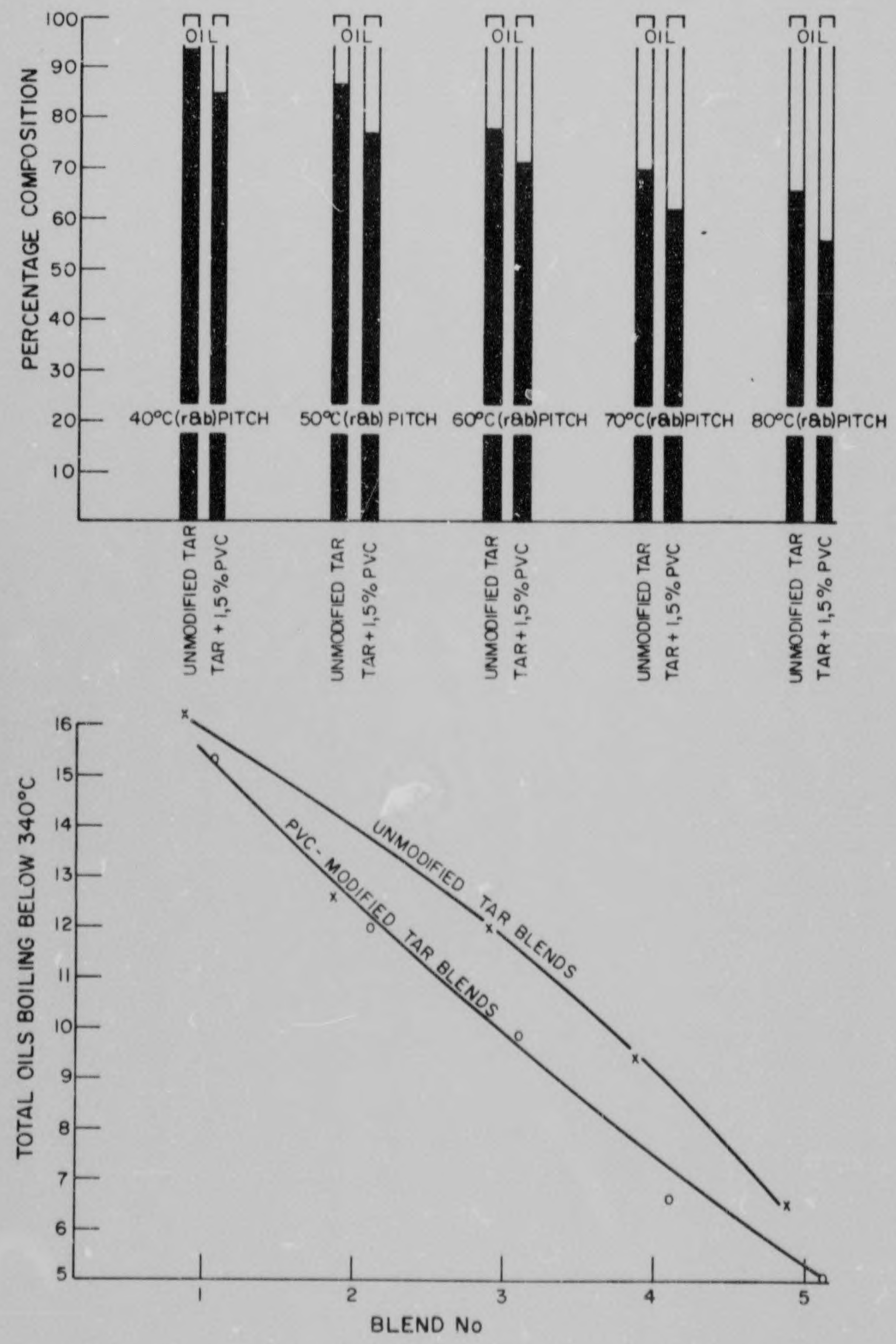

FIGURE 3-10

EFFECT OF PVC ADDITION ON THE COMPOSITION AND VOLATILE OIL CONTENT OF TAR BLENDS PREPARED FROM PITCHES OF VARYING HARDNESS

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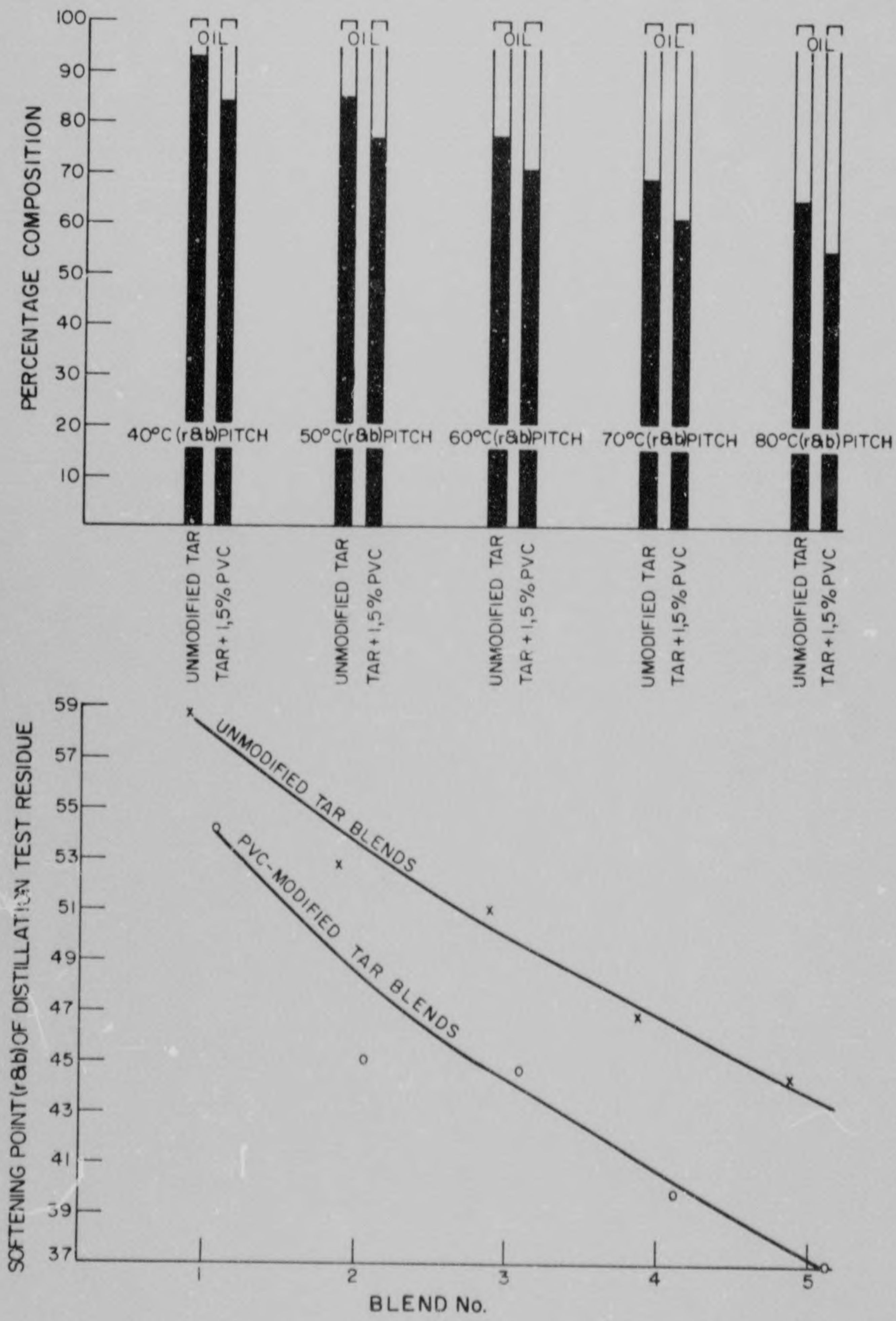

FIGURE 3-11

EFFECT OF PVC ADDITION ON THE COMPOSITION AND SOFTENING POINT OF DISTILLATION TEST RESIDUE OF TAR BLENDS PREPARED FROM PITCHES OF VARYING HARDNESS

TABLE 3 - 10

THE EFFECT OF STORAGE AT 110 °C ON THE DUCTILITY, ELASTICITY, AND BRITTLENESS OF A TAR MODIFIED BY VARIOUS POLYMERS (JAMIESON, 1968)

Hours storage	Ductility at 4 °C				Elastic recovery percentage Film thickness			Fraass brittle temperature			
	Tar only	Tar + Perbunan	Tar + Revinex	Tar + Revertex	Tar only	Tar + Perbunan	Tar + Revertex	Tar only	Tar + Perbunan	Tar + Revinex	Tar + Revertex
0	160+	129	160+	160+	28	347	135	-6,3	-6,8	-9,1	-6,8
24	160+	122	142	160+	-	320	78	-5,8	-7,6	-6,5	-6,5
48	-	-	92	133	8	-	89	-	-	-4,0	-
72	160+	-	83	84	-	200	89	-	-5,4	-	-3,6
96	160+	80	57	-	16	81	-	-4,3	-1,7	-0,2	-

TABLE 3 - 11

EFFECT OF STORAGE AT 110°C ON THE ELASTICITY

(ELASTIC RECOVERY) OF PVC/TARS

PVC/tar ex Supplier	Per cent PVC	Elastic recovery (percentage of film thickness)		
		Original	After 24h storage	After 96h storage
A	0	0	-	6
	0,75	138	155	135
	1,5	196	216	214
B	0	9	-	4
	0,75	153	156	154
	1,5	219	200	238
C	0	0	-	4
	0,75	138	125	133
	1,5	196	192	156

These results indicate that PVC/tars have adequate storage stability. They are also greatly superior to those obtained from the polymer-modified tars used in the earlier investigations.

It has previously been shown that the elastic recovery and ductility-tenacity tests measure different binder properties and that the latter is more meaningful in terms of the stone-retention properties of surface treatment binders. Accordingly, the measurement of the $^{W}/L$ ratio of tars and the effect of storage conditions on this ratio would be a useful way of assessing whether or not the outstanding properties, which make PVC/tar so attractive as a surface treatment binder , have been impaired.

A laboratory investigation was conducted in which PVC/tar was stored for 196 hours at 130°C, and as described in Appendix I, samples were recovered at various times over this period. The PVC-content, using the chemical determination of chlorine described in Appendix H, and the $^{W}/_{L}$ ratio of each sample were determined. The results are shown in Figure 3 - 12. The PVC (chlorine) content remained constant but the $^{W}/_{L}$ ratio fell during the 24-48 hour period, indicating degradation of the PVC. Thus the condition of the polymer in the tar cannot be reliably assessed from chemical determinations of the chlorine content. It was found that evolution of chlorine from PVC/tars could not be detected below 180°C although polymer degradation occurred below this temperature.

Storage stability tests were repeated at various temperatures in order to determine a safe maximum storage temperature. The investigation showed that the tar composition , in particular the volatility, influences the thermal stability. A low-volatile South African PVC/tar and an imported high-volatile blend were stored at 110°C for eight days using the procedure described previously. $^{W}/_{L}$ ratios of samples taken at intervals over the eight-day period are given in Figure 3 - 13. Whereas the high-volatile tar degraded significantly the low-volatile tar retained its ductility - tenacity over this period. (Distillation test results on the original binders are given in Table 3 - 12.) It may be concluded that 110°C is a safe temperature for storage of low-volatile PVC/tar blends.

TABLE 3 - 12

DISTILLATION TEST DATA DETERMINED ON A SOUTH AFRICAN LOW-VOLATILE PVC/TAR AND A HIGH-VOLATILE BRITISH PVC/TAR BLEND

Property	South African Low-volatile PVC/tar.	British High-volatile PVC/tar.
Evt	46,0	47,0
Distillation % m/m		
0 - 200°C	0,0	0,0
200 - 270°C	1,6	3,4
270 - 300°C	3,0	4,5
300 - 340°C	8,6	7,9
Total to 340°C	13,2	15,8
Softening point of distillation residue (r&b) °C	52,3	60,2

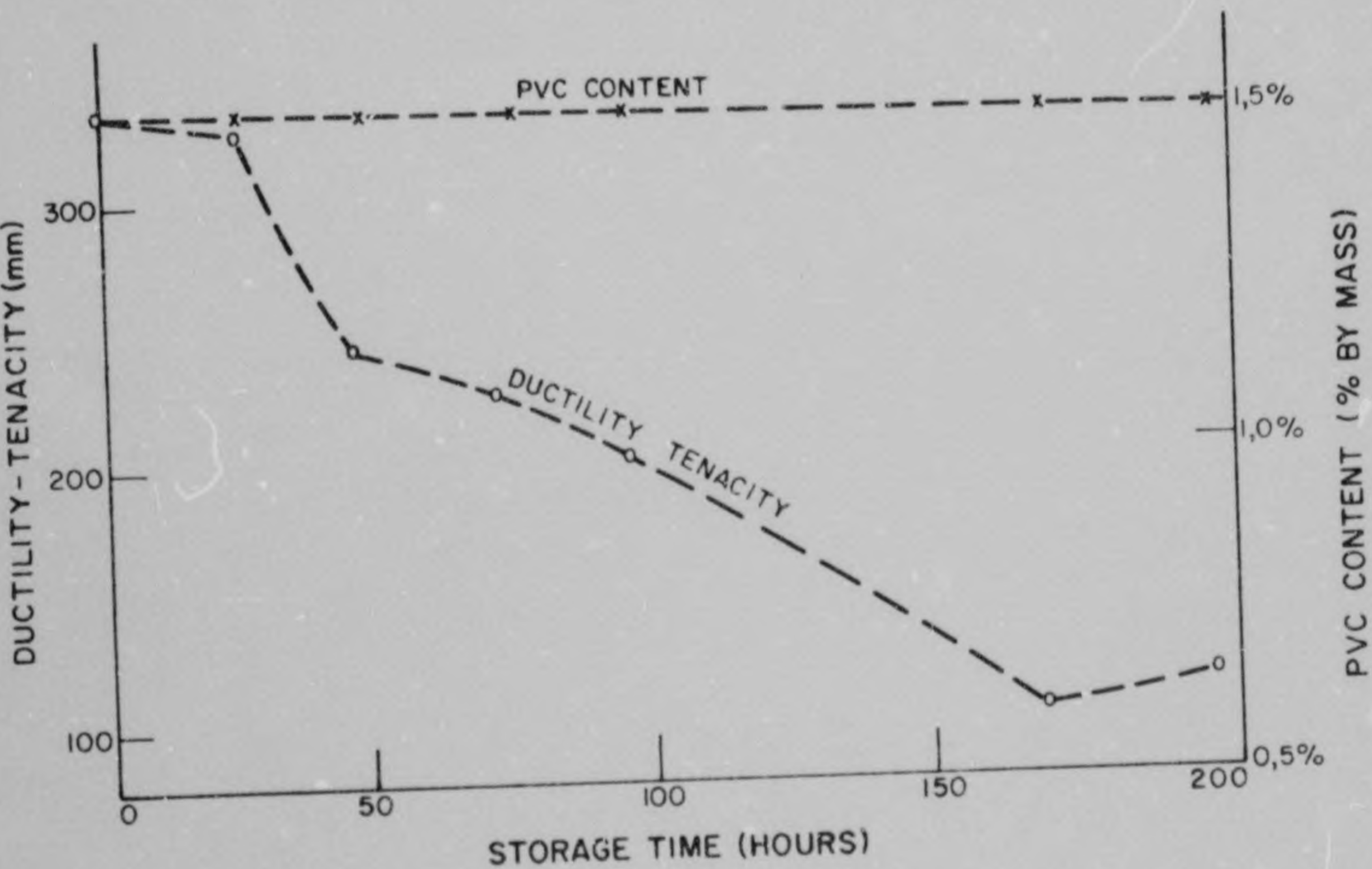

FIGURE 3-12

EFFECT OF STORAGE (AT 130°C) ON THE DUCTILITY-TENACITY AND THE "AS DETERMINED" PVC CONTENT OF PVC / TARS.

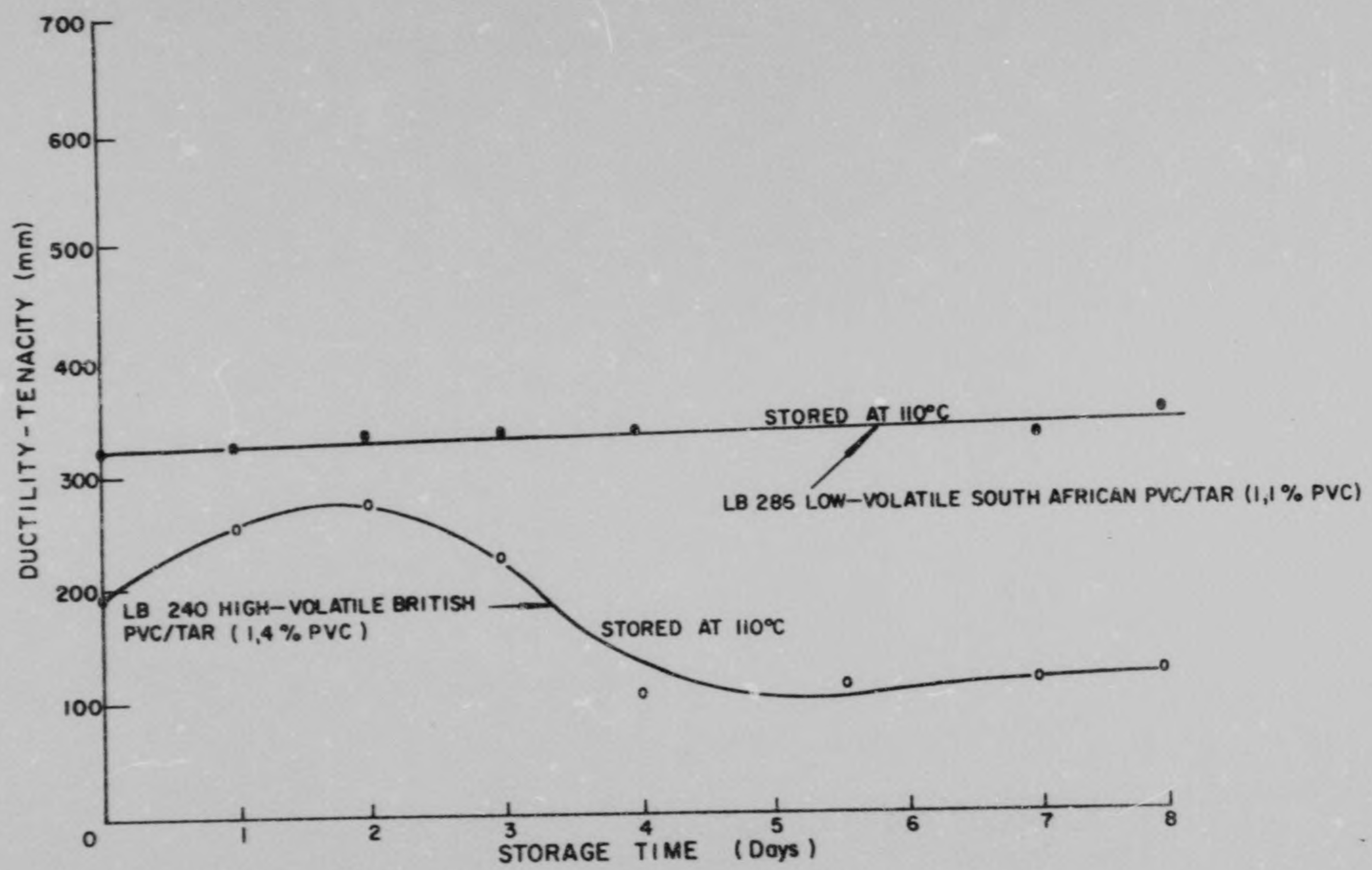

FIGURE 3-13

EFFECT OF HOT STORAGE ON THE DUCTILITY-TENACITY OF PVC/TARS

3.1.5 The performance of PVC/tar in single-surface treatments

It has been mentioned previously that the use of substitutes for road bitumens can mainly be justified on the basis of costs, and in Part 1, Chapter 2 it was estimated that for tar surface treatments service lives of about six years were necessary to be competitive. As PVC/tars are about 1 cent/litre more expensive than unmodified tars, this is certainly a minimum value.

Research on PVC/tar in South Africa started at the National Institute for Road Research, in 1968 and in view of initial results the binder became commercially available in 1969. In 1975 over 2 500 tonnes of the binder were used by road authorities. The average minimum service life of PVC/tar surface treatments will be of interest to maintenance engineers and the purpose of this section is to assess this , using the latest performance assessments both of experimental surfacings laid by NITRR and of surfacings constructed under normal resurfacings conditions.

Some of the experimental road surfacings were constructed prior to the commencement of the work described in this thesis. The performance of these sections was subsequently monitored by the author and these assessments have been used in this survey. These road experiments were:

(i) The 1968 small-scale experiment, Lynnwood Road, Pretoria. (Jamieson, I.L. and Edler, A.C. 1969).

(ii) The 1969 full-scale experiment, Sinoia, Rhodesia. (Alexander, C.D. et al. 1974).

(iii) The 1970 small-scale experiment, Lynnwood Road, Pretoria. (Jamieson, I.L. and Edler, A.C. 1971)

For this work the author constructed a full-scale experiment and two small-scale experiments, These were:

(iv) The 1972 full-scale experiment, Orkney-Bothaville.

(v) The 1972 small-scale winter experiment, Lynnwood Road Pretoria.

(vi) The 1974 small-scale experiment, Lynnwood Road, Pretoria.

The performance of the sections was assessed according to the Road Research Laboratory Method (1953) in which the following symbols are used.

Satisfactory condition			Unsatisfactory condition
VG (very good)	= with no discernible fault	F(fair)=	seriously faulted but still servicable
G(good)	= with no significant fault	P(poor)=	requires remedial treatment
FG(fairly good)	= only just acceptable	B(bad) =	requires immediate remedial treatment

Subscripts are used to explain departures from ideal (VG) behaviour.

Minus sign = loss of stone, Plus sign = excess binder

"v" = general variablity, "c" = cracking (degree of severity denoted on a numerical scale (1,3,or 5), "d" = deformation (severity denoted on a numerical scale 1,3 or 5).

Recently a method for the rating of pavement conditions has been devised which gives a more comprehensive description of the condition of a surfacing (Curtayne, 1974) and this is intended to assist the maintenance engineer to decide on the timing and nature of maintenance procedures. However, the RRL method was preferred in this study as it enables comparisons of the performance assessments of a large number of sections to be made at a glance.

The author assembled a team of experienced engineers to assess the surfacing condition and the results given in all cases are the average of at least six assessments.

3.1.5.1 Small-scale experiments

In initial experiments it was necessary to incorporate a large number of variables and for convenience it was decided to use a small-scale technique. The dimensions of each section are 3,7 m (or the width of one traffic lane) x 0,9 m (longitudinally). In the original work (National Institute for Road Research, 1959) the binder was applied by hand, i.e. using calibrated scoops the tar was poured onto a given area and carefully brushed into an even film using a paint brush. However, for this project a small-scale (mini) distributor was constructed to spray the binder onto the surface, i.e. to simulate the full-scale construction method. The mini distributor is illustrated in Figure 3 - 14 and described in Appendix J.

The aggregate was applied by hand-shovel and was well rolled-in by means of a heavy pneumatic-tyred vehicle. A Land Rover or Light Delivery

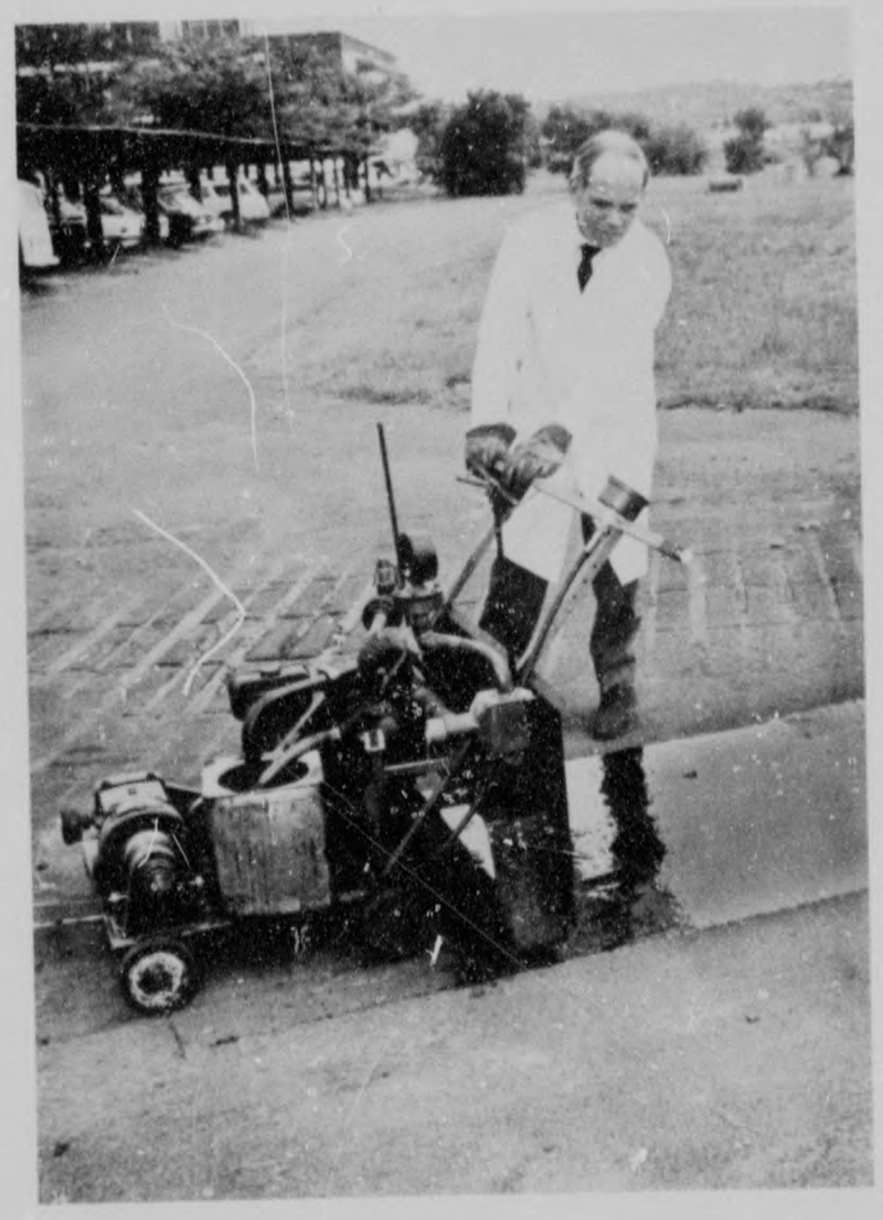

Figure 3 - 14: The mini binder distributor in operation.

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Van was used for this purpose.

The 1968 experiment

In this experiment tars supplied by three local manufacturers were used. Each supplied two Evt grades (45 - 50°C, and 50 - 55°C) and these were modified to contain 0,75 per cent, 1,0 per cent, 2,0 per cent and 2,5 per cent of the PVC at the original Evt. Cutback bitumen, 150/200 Pen. bitumen and tars modified with 0,75 per cent and 1,5 per cent of two types of synthetic rubber were used as controls.

It soon became apparent that the stone retention of the blends was different and this can be associated with differences in their volatility. At this time it was not realised that the volatility would override the beneficial effects of PVC addition. The most recent assessments (after six years' service) of all the sections is given in Appendix K (Section 1.1). After this assessment the road was reconstructed as part of a dual carriageway extension scheme of the Pretoria City Council.

This initial experiment showed that the performance of the PVC/tars was associated with their volatility.A plot of performance against PVC-content of three local tars is shown in Figure 3 - 15 and the distillation criteria of each of the original tars as received from the suppliers are indicated.

The following conclusions were drawn from the data given in Appendix K (Section 1.1) and Figure 3 - 15.

(i) The performance of PVC/tars from source B was superior and this was associated with the low volatility of these blends.

(ii) PVC and two synthetic rubber-polymers had a similar effect on the durability of low-volatile tars from source B.

(iii) Addition of PVC resulted in a significant improvement in the durability of the low-volatile tar and the performance of the surfacings improved with increasing PVC content of the tar up to the 2,5 per cent level.

(iv) Surfacings in which tar B contained 2,5 per cent PVC were in the same performance category as the bitumen surfacings which were satisfactory after six years' service.

It was also noted that the sections in which 45 - 50°C Evt viscosity grade blends were used performed slightly better than the sections constructed with 50 - 55°C Evt blends. The inference that low-Evt tars should be used where possible is discussed later.

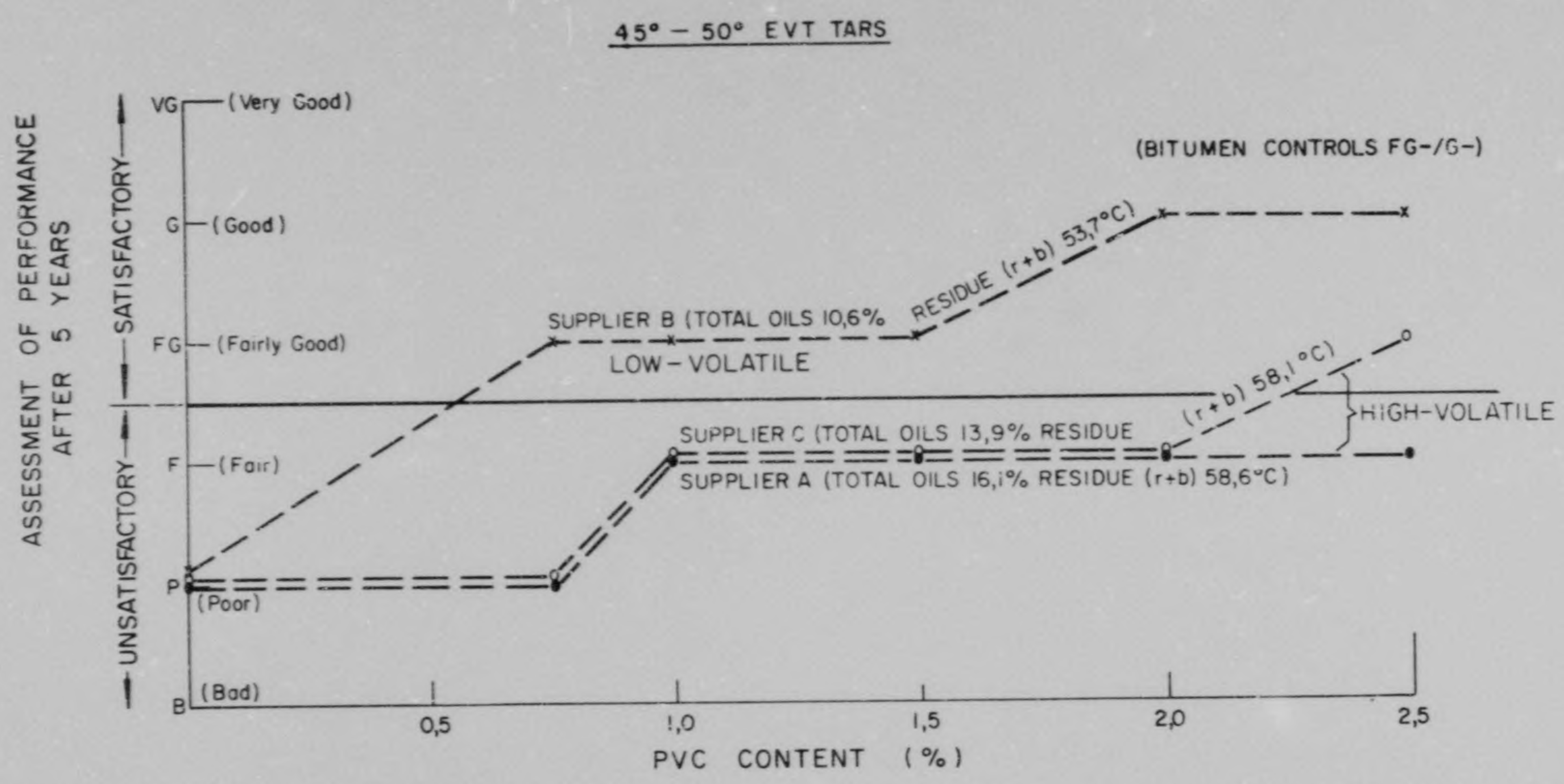

FIGURE 3-15

EFFECT OF VOLATILITY AND PVC CONTENT ON THE PERFORMANCE (AFTER 6 YEARS) OF 45-50° EVT TARS USED IN THE 1968 SMALL-SCALE EXPERIMENT LAID ON LYNWOOD ROAD, PRETORIA

When the pattern of results described above was noted, a study was made of all previous tar surface treatment experiments and this showed that performance could be related to the oils boiling below 340°C in the standard distillation test and the softening point of the distillation test residue.

The 1970 experiment

In order to confirm these results a further experiment was laid in which a series of tar blends was prepared spanning the proposed distillation test criteria. It was hoped that the results could be used to determine new limiting criteria for South African Bureau of Standards (SABS) and Central African Standards (CAS) tar specifications.

Two types of oil were used, differing slightly in volatility: a heavy tar-flux-oil (HTFO) and a light tar-flux-oil (LTFO)*. Another variable was the softening point of the pitch used with these oils and this varied from 40 - 80°C. Each series of blends was prepared with and without PVC. Where PVC was used the concentration was approximately 1,5 per cent. The layout of the experiment is described in Appendix K.

The proportions of oils and pitch of some of these blends, their distillation characteristics and performance, are summarised in Table 3 - 13. On comparing the performance of these surfacings with the distillation test data of the binders, the relationship between the volatility and the performance is again evident. Blends containing the highest proportion of the heavy plasticising oils performed best. Where PVC was incorporated the proportion of heavy oil used was even greater, as previously mentioned, (see Figure 3 - 10) and this resulted in an improvement in performance (the series of blends 1-5 is equivalent to the series 35-39 save for the presence of PVC, and hence the greater proportion of HTFO, in the latter). More recent assessments, after six years' service, show that the condition has not deteriorated since this assessment and hence low-volatile blends appear to give service lives of six years without difficulty.

Table 3 - 13 provides the manufacturer with suitable recipes for the preparation of 50 - 55°C Evt blends conforming to the limiting volatility criteria eventually chosen for this grade (maximum oils boiling below 340°C = 12 per cent and maximum softening point of distillation residue = 56°C .

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* THe HTFO had less than 10 per cent oils boiling below 340°C and the LTFO 40-60 per cent oils boiling below 340°C. These data were obtained using the creosote-oil distillation method, STPTC CO 3-67

** Actual specifications suggested for the coke-oven and Lurgi tars are given in Appendix L.

TABLE 3 - 13

COMPOSITION OF SOME BLENDS USED IN THE 1970 EXPERIMENT

AND THEIR PERFORMANCE AFTER VARIOUS PERIODS OF SERVICE

Sect. No.	Composition of Blend per cent by mass							PVC per cent	Distillation data		Performance* (Years)				
	Oil		Pitch (°C ring & ball)						Total oils boiling below 340°C	Soft. point of residue (r & b °C)					
	HTFO	LTFO	40°C	50°C	60°C	70°C	80°C				1	2	3	4	$6\frac{1}{2}$
1	7		93					0	16,1	58,8	G_-	F_-	P_-	B_-	B_-
2	15			85				0	12,6	52,8	G_-	G_-	FG_-	FG_-	FG_-
3	23				77			0	11,9	51,0	VG	G_-	G_-	FG_-	G_-
4	31					69		0	9,4	46,9	VG	G_-	G_-	FG_-/G_-	G_-
5	35						65	0	6,5	44,5	VG	G_-	G_-	G_-	G_-
35	16		82,5					1,5	15,3	54,2	VG	G_-	G_-	FG_-	G_-
36	23,7			74,9				1,4	12,0	45,2	VG	G_-/VG	VG	G_-	G_-/VG
37	29,2				69,5			1,3	9,9	44,7	VG	G-/VG	VG	G_-	G_-/VG
38	38,3					60,3		1,4	6,6	39,9	VG	G_-	VG	G_-	VG
39	45,0						53,6	1,4	5,1	37,1	VG	G_-	G_-	G_-	VG
17		5,0	95,0					0	15,3	-	FG_-	F_-	P_-	B_-	B_-
18		12,0		88,0				0	15,4	57,4	G_-	G_-	FG_-	F_-	P_-
19		18,0			82,0			0	13,0	51,5	G_-/VG	G_-	G_-	FG_-	F_-
20		26,0				74,0		0	10,9	48,9	G_-	VG	VG	G_-	FG_-
21		30,0					70,0	0	13,3	50,8	VG	VG	VG	G_-	G_-
51		12,0	86,5					1,5	18,1	57,5	VG	G_-	FG_-	P_-	P_-
52		18,7		79,9				1,4	13,6	50,7	VG	G_-	G_-	P_-	F_-
53		25,1			73,5			1,4	14,6	50,0	VG	G_-	VG	FG_-	FG_-
54		31,0				67,7		1,3	10,7	42,3	VG	G_-	VG	G_-	FG_-
55		36,0					62,6	1,4	12,9	48,0	VG	G_-/VG	VG	G_-	G_-

* The general condition of the surfacing is expressed on a six-point scale.

<u>Satisfactory condition</u>
- VG (very good) = with no discernible fault
- G (good) = with no significant fault
- FG (fairly good) only just acceptable

<u>Unsatisfactory condition</u>
- F (fair) = seriously faulted but still serviceable
- P (poor) = requires remedial treatment
- B (bad) = requires immediate remedial treatment

Subscript signs indicate the nature of the main faults;

+ = too rich in binder, - = loss of stone, v = general variability

The preparation of the low-volatile durable blends was facilitated by the use of high-softening point pitches. A relationship between pitch softening point and the performance is given in Figure 3 - 16. Blends containing pitches having softening points of 70°C and above gave the most satisfactory results. Analyses of Wilton pitches show that those having softening points of 40°C, 50°C and 60°C contain significant quantities of light oils (see Part 2, Figure 2 - 26).

Certain of the sections, including those mentioned in Table 3 - 13, were selected for subsequent monitoring of the viscosity and brittleness properties. These properties were determined by way of the sampling and testing procedures described in Part 2, Chapter 5. The results of Evt and brittle point determinations on the original binders and on the same binders after four years in service are given in Table 3 - 14. The change in Evt of the PVC/tars was independent of the pitch type but the blends prepared using LTFO increased in Evt to a greater extent than blends prepared using HTFO.

The most significant result was that, of the series of blends prepared with the low-volatile oil (HTFO), the unmodified and PVC-modified tars prepared from the hard pitches had the lowest brittle point temperatures after four years in service. These blends had a high plasticising-oil content of which a substantial proportion was due to the presence of the PVC. This confirms that the addition of PVC to road tars improves their durability due to the fact that its presence allows a greater quantity of heavy plasticising-oil in the blend.

In Chapter 3.1.3 the ductility-tenacity test was described and it was shown that PVC/tars have superior initial cohesive properties to unmodified binders and that more energy is required to dislodge chippings from a PVC/tar surface treatment than would be the case where unmodified tars were used. However, the results of the 1968 and 1970 experiments show that the weathering resistance of the tars is of overriding importance and that the durability of certain types of blends is inadequate.

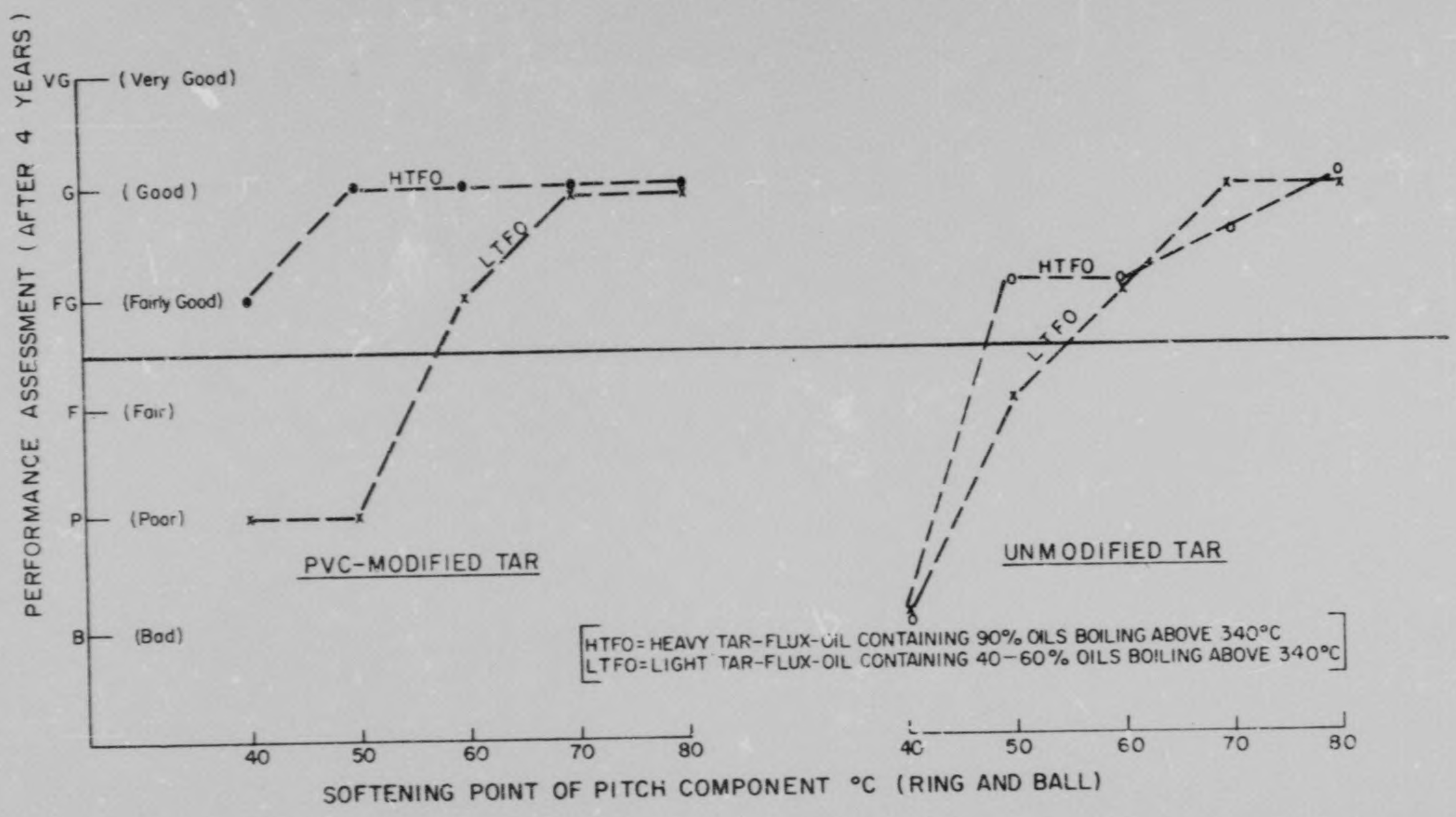

FIGURE 3-16

EFFECT OF THE SOFTENING POINT OF THE PITCH COMPONENT ON THE PERFORMANCE OF PVC/TAR BLENDS

TABLE 3 - 14

THE VISCOSITY AND BRITTLENESS OF BINDERS USED IN THE 1970 EXPERIMENT, RESULTS GIVEN BY SAMPLES OF THE ORIGINAL TARS AND BY SAMPLES RECOVERED FROM THE SURFACINGS AFTER 4 YEARS' SERVICE

Sect No.	Composition of Blend per cent by mass								Distillation data		Evt (°C)		Fraas brittle temperature (°C)	
	Oil		Pitch (°C ring & ball)					PVC	Total oils boiling below 340°C	Soft.point of residue (r & b)°C)	Original	After 4 years	Original	After 4 years
	HTFO	LTFO	40°C	50°C	60°C	70°C	80°C							
17		5,0	95,0					0	15,3*	-	52,4	82,2	- 8,5	-
18		12,0		88,0				0	15,4	57,4	52,5	79,9	- 8,5	+11,0
19		18,0			82,0			0	13,0	51,5	53,2	77,3	-11,5	+ 9,5
20		26,0				74,0		0	10,9	48,9	52,7	79,8	-12,0	+ 9,5
21		30,0					70.0	0	13,3	50,8	52,1	75,5	-11,0	+ 7.0
51		12,0	86.5					1,5	18,1	57,5	54,1	91,4	- 9,5	+20,0
52		18,7		79,9				1,4	13,6	50,7	53,7	84,3	-11,5	+14,5
53		25,1			73,5			1,4	14,6	50,0	53,9	86,9	-15,0	+16,5
54		31,0				67,7		1,3	10,7	42,3	54,3	89,3	-15,0	+14,5
55		36,0					62,6	1,4	12,9	48,0	5[illegible],6	-	-18,5	+20,0
35	16,0		82,5					1,5	15,3	54,2	54,7	81,3	-12,5	+11,0
36	23,7			74,9				1,4	12,0	45,2	54,6	82,8	-18,5	+ 9,5
37	29,2				69,5			1,3	9,9	44,7	54,0	82,0	-22,0	+ 8,0
38	38,3					60,3		1,4	6,6	39,9	54,6	79,4	-19,5	+ 5,0
39	45,0						53,6	1,4	5,1	37,1	51,5	80,7	-23,9	+ 4,5

* Calculated

The 1972 winter experiment

An initial winter application of low-viscosity low-volatile grades under normal resurfacing conditions resulted in a tendency for the surfacings to "bleed" in subsequent hot summer weather. This phenomenon may be attributed to the low-volatile characteristics of the binder resulting in a low evaporation rate and hence an insufficient Evt increase to obviate flow and run-off at higher road temperatures.

Obviously a winter grade PVC/tar requires:

1 Initial viscosity suitable to ensure complete stone retention
2 Volatility characteristics which will allow the Evt to increase sufficiently to prevent bleeding and run-off in hot weather
3 Satisfactory durability, i.e. the viscosity increase should not cause the tar to become brittle in cold weather or under fast traffic.

The purpose of the 1972 experiment was to find the blend composition which best satisfied these requirements. It was decided that the best approach would be to select a durable summer grade and cut this back to an Evt level suitable for use in winter months. It was hoped to vary the hardening rate (rate of increase in Evt) by using oils composed of various boiling point ranges. Blend 39, as used in the 1970 experiment was chosen as the ideal summer blend and cutting-back oils of varying volatility and fluxing power were obtained from a Wilton distillation plant: (1) Naphtha-oil, (NO), (2) wash-oil (WO), (3) tar cutback-oil (TCBO), (4) light tar-flux-oil, (5) heavy tar-flux-oil.

Using the above materials, PVC/tar blends of 36°C Evt and 42°C Evt were prepared. The Evt was selected on the basis of the expected minimum road temperature at the time of laying, July. (This procedure is described in detail in Part 3, Chapter 1.6.) The layout of the experiment, composition of flux-oils, blends, and performance assessments are given in Appendix K, Section 1.3, Tables 1 to Vll.

Initial results demonstrated the importance of the selection of the initial Evt of the binder. In control sections the unfluxed blend 39, i.e. Evt 52°C, lost more than 50 per cent of the stone during the first night after the application as shown in Figure 3 - 17.

The Evt of the binders used in this experiment was monitored and the effect of the various cutting-back oils on the rate of hardening of the blends in the first 12 months is given in Figure 3 - 18.

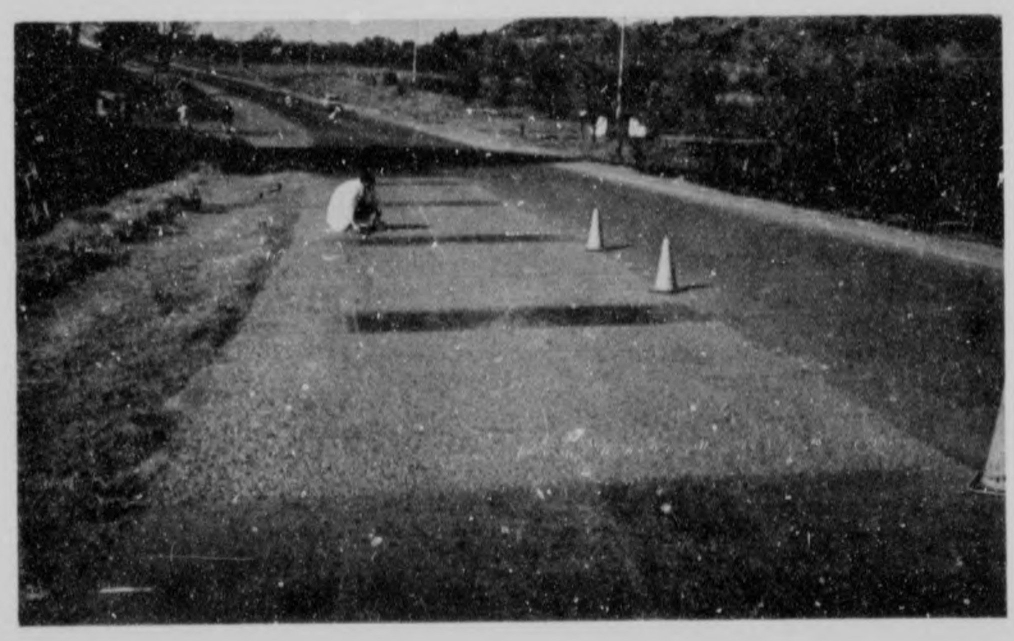

Figure 3 - 17: View of the 1972 'Winter' experiment on the day after construction. Severe loss of stone occurred overnight from sections on which a tar was used having too high an EVT (50-55° C) for the prevailing temperature conditions (the air temperature dropped to —1° C).

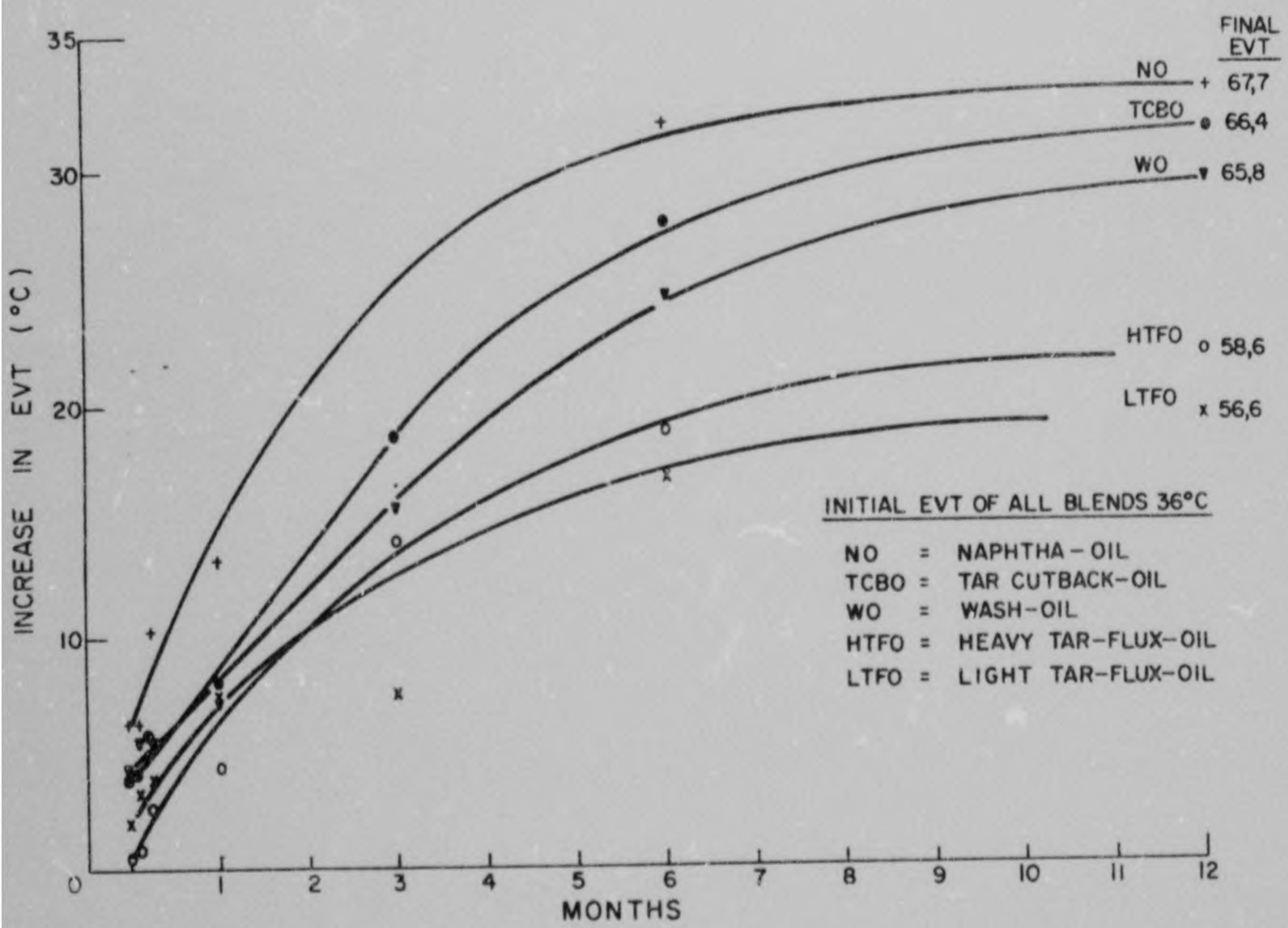

FIGURE 3-18

EFFECT OF VARIOUS CUTBACK-OILS USED IN PREPARING ROAD TARS ON THE INCREASE IN VISCOSITY OF THE TARS IN SERVICE

The blend containing the very light naphtha-oil hardened most rapidly; in the initial stages the hardening was about 50 per cent more than in the other blends, and this probably explains the slightly less satisfactory nature of the surfacings constructed with this blend. In any event the use of this oil for this purpose cannot be recommended in view of the deleterious effects of phenolic substances contained in these oils as described in Part 2, Chapter 5 (see Figure 2 - 37).

It was also apparent that blends in which only the HTFO and LTFO cutting-back oils were used gave rise to distinct fatty areas and some "run-off" at the road edge.

From the performance to date it would appear that the TCBO and WO types may be most suitable for use in the preparation of the winter grades from durable summer grades.

The following recipe for a 36°C Evt tar would be appropriate for winter conditions on the South African Highveld.

Heavy tar-flux-oil (90 per cent oils boiling above 340°C STPTC Method CO 3-67)	= 41,0 per cent
Tar-cutback-oil (90-95 per cent oils boiling between 200-300°C. STPTC Method CO 3-67)	= 9,5 per cent
Pitch (Softening point 80°C (ring and ball))	= 48,0 per cent
PVC -("Corvic" D60/11)	= 1,5 per cent

The distillation test results given by such a blend were:

0 - 200°C	= 0,0 per cent by mass
200 - 270°C	= 8,3 per cent by mass
270 - 300°C	= 2,2 per cent by mass
300 - 340°C	= 7,7 per cent by mass
Total oils to 340°C	= 18,2 per cent by mass
Softening point (ring and ball) of residue at 340°C	= 40,6°C

It will be observed that although the volatility of the blend was increased, the softening point of the distillation test residue was very low, (indicative of a high plasticising-oil content) which augurs well for the durability of the blend.

This experiment also showed that the use of smaller stone sizes, and hence thinner binder films, gives a more rapid initial hardening rate which may be appropriate for winter months. A 13,2 mm Reef Quartzite required an application of 1,20 l/m^2 whereas a slightly smaller Pretoria Norite needed a 0,82 l/m^2 application which caused a significantly greater increase in viscosity over the period July - October, as shown in Table 3 - 15.

TABLE 3 - 15

WINTER PVC/TAR BLENDS

EFFECT OF BINDER FILM THICKNESS ON THE INCREASE IN VISCOSITY OF THE BLENDS OF NOMINAL EVT 36°C AFTER 3 MONTHS' SERVICE

Blend	Increase in Evt (°C) for application of:	
	0,82 litre/m^2	1,20 litre/m^2
Blend 39 + LTFO	15,1	7,6
Blend 39 + HTFO	16,6	14,2
Blend 39 + TCBO	25,5	18,7
Blend 39 + NO	29,8	23,5
Blend 39 + WO	22,4	15,6

The 1974 experiment

It was mentioned previously that in the 1968 experiment the lower of the two Evt grades of tar used performed better than the higher Evt grade.

The results of monitoring tests on PVC/tar binders laid on certain Johannesburg streets showed that the 40-45°C Evt blends applied in winter were considerably softer than the 50 - 55°C Evt blends after an equal period in service. These results are given in Table 3 - 16.

As distress of surfacings in the form of cracking and loss of stone is due to excessive hardening of the binder, it is logical to expect that the use of lower viscosity grades will extend the service life , assuming that the constitution is such as to restrict the rate of hardening.

The purpose of the 1974 experiment was to determine the lowest Evt grade tar that could be used, in summer conditions, which would completely retain the stone at the highest expected road temperatures during the initial life of the surfacings. The maximum road surface temperature during this period was 62°C and four Evt grades of PVC/tar were used; 35 - 40°C, 40 - 45°C, 45 - 50°C and 50 - 55°C Evt. The layout of the experiment, properties of the blends and performance assessments are given in Appendix K, section 1.4, Tables VIII to X.

TABLE 3 - 16

ANALYSES OF PVC/TARS RECOVERED FROM SURFACE TREATMENTS

LAID IN SUMMER (FEBRUARY) AND WINTER (JULY) 1971 IN JOHANNESBURG

Street	Original properties		Properties of binder recovered after:													
			3 months		4 months		5 months		6 months		1 year		15 months		2 years	
	Evt (°C)	Fraass (°C)	Evt (°C)	Fraass (°C)	Evt (°C)	Fraass (°C)	Evt (°C)	Fraass (°C)	Evt (°C)	Fraass (°C)	Evt (°C)	Fraass (°C)	Evt (°C)	Fraass (°C)	Evt (°C)	Fraass (°C)
Laid in Summer (February)																
5th Road, Greymont	50,7	-19,0	61,6	- 9,5	63,5	11,0	65,7	-11,4	64,5	- 6,5	71,0	-3,0	-	-	74,8	+ 2,0
Laid in winter (July)																
Rose Avenue	43,5		51,8	-17,0	55,8	-14,5			58,0	-13,5			62,1	- 6,0	62,5	- 6,5
Tyrrwhitt Avenue	39,5		51,9	-17,0	58,6	-16,5			58.7	-14,5			64.0	- 7,0	67,1	- 3,0
Reform Avenue	39,5		44,7	-17,0	52,2	-16,5			53,2	-14,5			53,8	-16,0	57,0	-11,5

In the small-scale experimental sections, in which the chippings are more generously applied than normal, all Evt grades successfully retained the stone. There was some initial "run-off" but in subsequent hot weather no bleeding occurred, and at this stage all these sections are in a satisfactory condition.

For full-scale work it cannot be recommended that PVC/tars having Evt's as low as 35°C should be applied at road surface temperatures typical of the Transvaal summer. It is conceded that the problems of "whip-off" may be more severe on a full-scale section than they are on the small-scale section. However, the results of the small-scale work are perhaps sufficient to show that viscosity grades lower than those used currently should be considered for summer work and that engineers may be advised to err on the low viscosity (Evt) side.

3.1.5.2 Full-scale experiments

In addition to field trials two full-scale experiments were laid.

The Sinoia (Rhodesia) experiment, October, 1969

This experiment was the first properly controlled full-scale experiment in Southern Africa and was laid at the request of the Rhodesian Ministry of Roads. The author assisted in the formulation of the binder, and in the experimental design and during the construction.

The variables investigated were the rate of application, and the effect of precoating the stone. Unmodified coke-oven tar and cutback bitumen were used as controls. The layout of the experiment and performance assessments are given in Appendix K, Table X1.

At the most recent assessment, five years after laying, the PVC/tar sections were rated in the same main category as the bitumen control sections. These results have been reported in detail by Alexander et al. (1974).

The Orkney-Bothaville experiment, March 1972

The experiment was constructed with the assistance of a maintenance crew supplied by the Orange Free State Provincial Roads Department. Each section comprised the full width of the road and measured 100 m in length. There were 119 sections in all, i.e. the experiment covered a distance of approximately 12 km, and the section of route P43/2 chosen was particularly suitable being very straight and flat with only one "tight" bend in the entire length.

Although the main purpose of the experiment was to evaluate PVC/tar in single-surface treatments, some sections of double-surface treatments were included and a number of small-scale sections were also constructed to confirm that the small-scale techniques gives results in agreement with full-scale performance.

The layout of the experimental sections is given in Figure 3 - 19. The properties of the binders and performance assessments are given in Appendix K, Tables X11 and X111 and a full description of the construction of the experiment has been given by Jamieson and Visser, (1973).

After four year's service the PVC/tar single-surface treatments are satisfactory with respect to stone loss but severe cracks originating in the base layers occurred on various parts of the experimental sections. These cracks are more visible in sections on which smaller stone sizes have been used. The performance of the PVC/tars and bitumen in the study of the effects of the construction variables may be summarised as follows:

1	<u>Effect of binder source</u>	<u>13,2 mm stone</u>	<u>9,5 mm stone</u>
	Dundee PVC/tar (0,92 to 1,85 l/m^2)	G_- to G_+	-
	Iscor PVC/tar (0,98 to 1,69 l/m^2)	G_{+v} to VG	G_{+c3} to G_+
	Bitumen (0,98 to 1,52 l/m^2)	G_+ to VG	G_- to VG

2	<u>Effect of graded versus single sized 13,2 mm stone</u>	<u>Graded</u>	<u>Single-sized</u>
	Iscor PVC/tar	G_+	G_+
	Bitumen	VG	G_- to G_+

3 <u>Effect of rolling techniques</u>

	4 Passes heavy pneum.	4 Passes heavy pneum	4 Passes heavy pneum + 1 pass flat	4 Passes heavy pneum. + 1 pass flat	2 Passes flat
		<u>13,2 mm stone</u>			
Iscor PVC/tar	G_{+v} to FG_-	G_+	G_{-v} to G_{+v}	G_{-c3} to G_{+c1}	G_{-v} to G_+
Bitumen	G_+ to VG	G_-	G_-	G_- to G_{+v}	G_-
		<u>9,5 mm stone</u>			
Iscor PVC/tar	FG_{-c5} to FG_{-c3}	FG_{-c5} to FG_{-c3}	FG_{-c5} to FG_{-c3}	FG_{-c5}	G_{-c1}
Bitumen	G_{+c1} to G_+	G_- to G_+	G_{-c1} to G_{+c1}	G_{-c1} to G_{+c1}	G_{-c1} to G_-

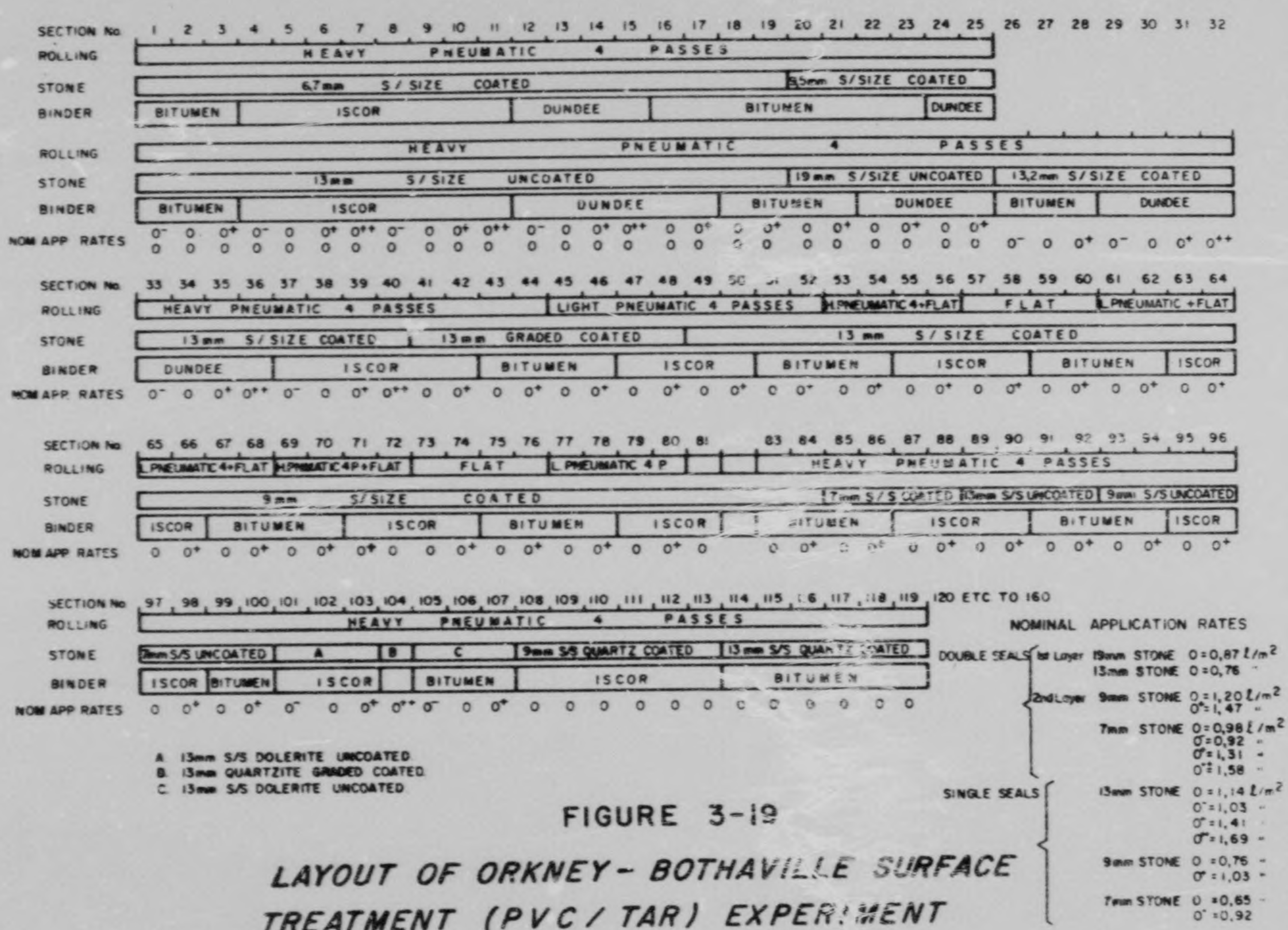

FIGURE 3-19

LAYOUT OF ORKNEY - BOTHAVILLE SURFACE TREATMENT (PVC / TAR) EXPERIMENT

4 effect of stone size and type

	13,2 mm	9,5 mm	6,7 mm
a. quartzite (coated)			
Iscor PVC/tar	G_{+V} to VG	FG_{-c5} to FG_{-c3}	F_{-c5} to FG_{-c5}
Bitumen	G_{+} to VG	G_{+c1} to G_{+}	FG_{+c5} to FG_{+}
b. quartzite (uncoated)			
Iscor PVC/tar	G_{-c3} to G_{-c1}	FG_{-c5} to FG_{-c3}	FG_{-c5}
Bitumen	G_{-} to G_{+}	G_{-c3} to G_{-c1}	FG_{-c5} to FG_{-c3}
c. dolerite (uncoated)			
Iscor PVC/tar	G_{-} to VG		
Bitumen	G_{+} to VG		

There was no difference in performance between PVC/tars prepared by the two suppliers after four years in service.

The stone retention on the bitumen sections appeared to be slightly better than on the PVC/tar sections and it is clear that the PVC/tar performed less satisfactorily than bitumen when less than the optimum application was used. However, the best PVC/tar sections were equal in performance to the best bitumen sections. It was noticeable that the PVC/tar seemed to perform less satisfactorily when smaller stone sizes were used and this may be because of the more rapid hardening exhibited when a light application of binder was used, as shown in Table 3 - 15.

The more critical nature of binder application when using tar binders was shown after the first twelve months when the sections on which thick tar applications were used exhibited a slight "fattiness". This was more pronounced on the southbound lane than on the northbound, which was consistent with the heavier axle loads on this lane, see Appendix K, Tables XlV and XV.

The variations in the stone grading or rolling techniques have had no significant effect on performance at this stage. The precoating of the aggregate did not improve stone retention.

3.1.5.3 Normal maintenance resealing operations

The results of the road experiments showed that low-volatile tar characteristics are mandatory for the adequate durability and performance of PVC/tars. To this prerequisite it may be added that laying conditions must be suitable and good construction techniques must be applied. These are necessary for the satisfactory performance of all surface treatments irrespective of the type of binder employed.

Road authorities often suspect that results obtained in road experiments can be misleading because of the particular care taken during the construction phase, whereas in normal construction processes the engineer cannot always afford to devote such particular attention to safeguarding a material. Because of this a study was made of the behaviour of PVC/tars constructed under normal, as distinct from experimental, working conditions. Certain surfacings were selected for study and only cases where a full record of binder test properties and of the construction work itself was available were considered.

Newcastle-Volksrust (former N3 section 7)

This road was resealed in February 1969 and these surfacings are the longest surviving (eight years) full-scale PVC/tar sections in the country. As a result of the considerable industrial expansion in the area, a large portion of the original 16 km has been widened and overlaid by a wearing course. The condition of most of the remaining surface treatment is satisfactory though the road is structurally inadequate.

Newcastle-Ladysmith

Approximately 50 km of single-surface treatment maintenance was carried out on this route, using PVC/tar, between 1970 and 1972. Though this was later overlaid (1975) as part of a road widening and improvement scheme, the performance of the sections was excellent at that stage.

Newcastle-Utrecht

The PVC/tar surface treatment was constructed in 1972 and this route has also recently been reconstructed. The surface treatment was last inspected in July 1975, at which time the surfacing was in excellent condition although the existence of structural problems was very evident.

Pretoria-Warmbaths (TPA* experiment)

Sections of PVC/tar were constructed on this route in December 1974, by the Roads Department of the Transvaal Provincial Administration. The purpose of the work was to assess the value of precoating the aggregate. Sections of bitumen were also constructed to give a

* Transvaal Provincial Administration

comparison of performance with the two types of binder.

Both the tar and bitumen seals showed signs of impending failure during the initial winter period and this is ascribed, at least in part, to too thin an application of binder. Standard test properties of the PVC/tar, given in Appendix K, showed up certain faults in the binder. The PVC content was only 1 per cent, the distillation characteristics were borderline and the anthracene content was high (3,4 per cent as against the stipulated maximum of 3,0 per cent). Condition assessments were made by the TPA in March 1975, and subsequently by the author at the end of the following winter, (August 1975). It was apparent after the latter inspection that the sections showed particularly heavy stone loss in cold spots such as dips in the road and near culverts. That this occurred with the bitumen as well as with the tar is thought to be due to the fact that the application may have been too low in this case.

Results of Evt monitoring tests are given in Appendix K, Figure 3.

Suburban streets in Johannesburg

About 365 000 m^2 of suburban streets were resurfaced using PVC/tar in 1970 and 1971. Results of initial and recent performance assessments of surfacings for which all the data is available are given in Table 3 - 17. The results of standard tests conducted on the tars are given in Appendix K, Table XVll. All the tars complied with the proposed specifications governing the volatile-oil content and the hardness of the distillation residue, and all the surfacings are in a satisfactory condition at this stage.

In addition, the performance of about two-thirds of all other PVC/tar work done in Johannesburg at this time was monitored and, with the exception of some streets which were resurfaced in winter, they are mainly satisfactory (after 5 - 6 years' service). The PVC/tar used on these streets was not examined for compliance with low-volatile test criteria).

The results given by streets resurfaced during the period December 1970 - April 1971 are shown in Appendix K, Table XVlllA. These indicate that the success rate is approximately 85 per cent at this stage. One street, Fortesque Street, Yeoville, had to be resealed one year after the initial application due to severe stone loss. It is significant that this street was the first to be resealed in the summer period (1st April, 1971) at which time there was a sudden onset of cold weather as is shown by air temperature records given in Appendix K, Figures 4 and 5.

TABLE 3 - 17

RESEALING OF SUBURBAN STREETS IN JOHANNESBURG

PERFORMANCE OF PVC/TAR SURFACE TREATMENTS IN WHICH

THE PVC/TARS ARE KNOWN TO COMPLY WITH THE AUTHOR'S SPECIFICATION FOR LOW-VOLATILE TARS

Street	District	Construction date	Spray application $1/m^2$	Binder sample	Assessment**			Remarks
					Dec 1971	July 1973	Oct. 1976	
Portland Ave.	Craighall Pk.	15/1/51	1,14	TJ1	-	G_V	FG_{-V}	-
Bedford Ave.			1,14		-	G_+/VG	FG_{-V}/G_{-V}	
Cambridge Ave.			1,09		-	G_+	FG_{-V}/G_{-V}	
Beaufort Ave.			1,25		-	G_-/VG	G_-/VG	
Wychwood Rd.,	Forest Town	26/1/71	1,09	TJ2	-	G_-	G_-	
Epping Rd.			1,09		-	VG	G_-	Some spray overlapping at the centre line
Waltham Rd.			1,09		-	G_V	G_-	Some fatty patches
Restonwold Dr.	Saxonwold	27/1/71	1,09	TJ3	-	G_V	G_{-vcl}	-
Albert St.	Newlands	5/2/71	1,09	TJ4	-	G_V	G_-	-
Van Zyl St.			1,09		-	G_+	G_-	A bare strip in centre of road
Garden St.			1,09		-	G_-	G_-	
Meyer St.			1,36		G_-	G_V	G_-	Old surface badly deformed
Kei Rd.	Emmarentia	12/2/71	1,09	TJ5	-	G_-	G_-	-
Visser Rd.	Montgomery Pk.		1,09		-	VG	-	-
5th Road	Greym[illegible]	11/2/71	1,09	TJ6	G_-/VG	G_V	G_V	Very steep hill- old surface deformed
12th Street			1,09		G_-/VG	VG	G_+	Old surface badly deformed
13th Street			1,09		G_-/VG	G_+	G_-	Old surface badly deformed
Winslow Rd.	Parkwood	27/1/71	1,09	TJ7	-	G_-	G_-	-
Westwold Way			1,09		-	VG	G_+	-
Moseley Ave.	Auckland Pk.	19/2/71	1,03	TJ8	VG	G_V	G_-	Slightly fatty at centre line due to spray overlap
Dordrecht St.	Crosby	26/2/71	1,03	TJ9	VG	VG	G_-	-
Baldoyle Ave.			1,14		VG	G_V	FG_{-V}	-
Rosina Rd.	Turffontein	19/3/71	1,09	TJ10	-	G_+	G_{-V}	-
Corner St.	Forest Hill		1,09		-	G_V	G_V	-

* For standard test properties see Appendix K

** For an explanation of the symbols see Chapter 3.1.5

On this road the stone loss was particularly bad at localised (cold) spots, e.g. under trees, and this is indicative that the binder viscosity was too high for the road temperature conditions prevailing immediately after the construction.

Incorrect selection of binder viscosity was also responsible for the initial stone loss that occurred in surfacings constructed during the winter months (June - August, 1971). Where attempts were made to reduce the Evt of the binder, severe bleeding occurred on some roads during the subsequent summer season and this problem was increased on roads having a poor profile where the binder tended to gather in depressions forming "puddles". (The development of suitable grades of tar for winter applications has been described.) However, those surfacings which survived these earlier problems are still in excellent condition, as shown in Appendix K, Table XV111B and the results of Evt monitoring tests which were described earlier, Table 3 - 16, indicate that these surfacings may prove to be more durable than surfacings laid in winter. These results support the contention that in surface treatment work the Evt of the tar should be as low as possible and that PVC/tar may prove to have a further advantage over unmodified tar in this regard because of its superior ductility-tenacity.

The performance of surface treatments constructed in Johannesburg at about the same time using MMC5 cutback bitumen has also been monitored. These performance assessments are given in Appendix K, Table XV111C. Both types are satisfactory and the best PVC/tar surface treatments have been assessed as VG (after five years), which is a superior category of performance to the best assessment of the cutback bitumen surface treatments.

3.1.6 Practical aspects of the construction of PVC/tar single-surface treatments

The results of road experiments in South Africa show that the performance of low-volatile PVC/tar is excellent. From the work which has been described and from experience in constructing PVC/tar surface treatments, the benefits in the use of PVC/tar may be summarised as follows.

(i) It is more durable than unmodified tar and may even give a service life equivalent to that of bitumen. The price advantage which PVC/tar has over bitumen can lead to savings even if the service life of the PVC/tar is slightly shorter.

(ii) Due to the strong initial adhesive-cohesive properties of PVC/tar a road surface treated with this binder can be opened to normal traffic conditions more quickly than is the case with conventional binders.

(iii) Because of the tenacious property of the binder, initial stone loss from freshly laid surfacings is reduced and windscreen damage almost completely eliminated. On driving over a stretch of road which has recently been surface-treated partly with PVC/tar and partly with bitumen or unmodified tar, the greater ability of the PVC/tar to retain the chippings is clearly demonstrated.

(iv) Where PVC/tar, rather than conventional binders, is used, stone is less likely to be stripped from freshly laid surface treatments during summer rain showers. However, this only applies when conditions are sufficiently warm to allow the wet stone to dry rapidly.

In addition to the above, French workers (Rofidal, 1967) have claimed that PVC/tar is less susceptible to bleeding than other binders.

Other claims, that the binder permits an extension of the period during which surface treatments can be laid and allows the use of lighter applications, have been found to be ill-founded in South African conditions. Despite the good performance of PVC/tars in seals and the advantages listed above, it cannot be said that that they have proved successful in all cases. To some degree this has been due to a lack of understanding of the advantages of PVC/tar and of the precautions which should be taken to ensure that it is used successfully. McNeil (1970a) emphasised this point and mentioned that difficulties had arisen through the over-enthusiasm of observers on viewing the initial toughness and elasticity of the binder for the first time.

In the following sections guidelines are given for the successful application of PVC/tar single-surface treatments.

3.1.6.1 Selection and identification of roads suitable for the application of PVC/tar surface treatments

(i) In general the use of PVC/tar is most appropriate in areas of of the country where it is cheaper than petroleum bitumens or bitumen emulsions.

(ii) As it has been shown that the addition of PVC brings about a significant improvement in the weathering resistance of tar It follows that it should be added in all cases where a maximum service life is required of a single-surface treatment constructed with coke-oven tars.

(iii) Recommendations (i) and (ii) apply irrespective of the traffic volume.

(iv) In Europe, PVC/tar has been advocated for work in which its outstanding initial elasticity and tenacity can be used to good effect. In South Africa no other commercial binder has comparable initial properties and there are certain areas in which surfacings are subjected to high traffic stress where these properties can be used to advantage.

These are :

(a) Steep inclines* ;

(b) Sharp bends ;

(c) Approaches to stop or yield signs;

(d) Approaches to robots and roundabouts; and

(e) On the off-ramps of freeways.

(v) Because of its superior initial cohesive properties, PVC/tar can be used in areas where interruption of the normal flow of traffic by the maintenance operation can least be tolerated.

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* On a steep incline of route P1/2, the old Johannesburg-Pretoria road, PVC/tar achieved complete stone retention after other binders had proved unsuccessful. On this steep incline, near Six-Mile Spruit, a surface almost bare of chippings had resulted and this was very slippery in wet weather. Sealed with PVC/tar in 1972 this is at present in excellent condition

(vi) It may also be recommended for roads on which the presence of loose chippings is least acceptable. It should therefore be considered for important trunk roads and even for motorways. Since 1963, single-surface treatments have been used to restore the non-skid properties of some British motorways, (Robinson, 1969). PVC/tar was used in 1968 for resealing the elevated sections of the M4 in London. This reduced the number of skidding accidents in wet and dry conditions (by 75 and 50 per cent respectively.

(vii) The viscosity of tars is more susceptible to changes in temperature than is the case with bitumen. The effect is reduced in the case of PVC/tars. Because of this factor tars can be used most effectively in areas where annual temperature variations are least; such as in the coastal and lowveld areas.

(viii) It is well known that surfacings in which tar binders are used are very resistant to the solvent effects of oil and diesel fuel. PVC/tars have been reported to be even more resistant than unmodified tars and large quantities of PVC/tar concretes have been used for this purpose in Europe, (Holden and Williams, 1975). PVC/tar surface treatments may thus be considered for areas in which it is important to have a high resistance to the effects of fuel spillage.

(ix) The performance of recently laid PVC/tar surfacings is not adversely affected by sudden thunderstorms such as those often experienced in summer rainfall areas, e.g. the Highveld. However, this usually only applies when some compaction has taken place and when the temperature is sufficiently high to allow the surface to dry rapidly.

3.1.6.2 Selection of the viscosity grade

The most frequent cause of the premature failure of a surface treatment is the selection of an incorrect viscosity grade. Usually this occurs when the ambient temperature is too low for the viscosity of the binder used. To ensure adequate wetting during the construction period, the viscosity should not rise above 10^4 Ns/m^2 (Briggs, 1970) In the author's view this viscosity should not be exceeded during the first week after construction as the passage of traffic will cause stone to be whipped off where it is not properly wetted or gripped by the binder. The importance of using a binder with a sufficiently low Evt was shown in the 1972 winter small-scale experiment where, because of low road temperatures, most of the stone was lost from sections constructed using the 50 - 55°C PVC/tar, whereas those constructed using 36°C and 42°C Evt tars were able to retain all the stone.

On the other hand, the Evt should not be too low as this may cause the tar to drain away from the stone where there are steep inclines or cambers or where the existing pavement is badly deformed. Low viscosities may also render the surfacing more susceptible to bleeding should there be an over-application of the binder.

One method, for computing the appropriate Evt suggested by the author is based on that developed by workers at the Coal Tar Research Association (now the British Carbonisation Research Association). By this method the maximum Evt is derived from:

Maximum Evt = minimum road surface temperature in period subsequent to laying + C

(where C = 40°C for PVC/tar and bitumen,
= 32°C for unmodified coke-oven and Lurgi tar.

The minimum Evt is derived from:

Minimum Evt = mean daily road surface temperature + 5°C

This method results in an Evt range and, in view of the relatively high increase in viscosity exhibited by tars, it is suggested that the chosen Evt should be at the lower end of this range. It may be that this method of determining the minimum Evt is not altogether suitable for South African conditions and certain anomalies seem possible. However, the method for the selection of the maximum permitted Evt grade is satisfactory. Suggested maximum Evt grades for Pretoria throughout the year have been computed from typical temperature data as shown in Figure 3 - 20.

Tar binders may harden on storage especially when prolonged delays occur. Where hardening is suspected, the use of the trough viscometer (Jamieson, 1976) to check the Evt is recommended. This instrument is simply constructed and the only additional equipment required is a stop watch and a means (gas burner or primus stove) of raising the water-jacket temperature.

In areas where excessive turning movements occur, a higher viscosity

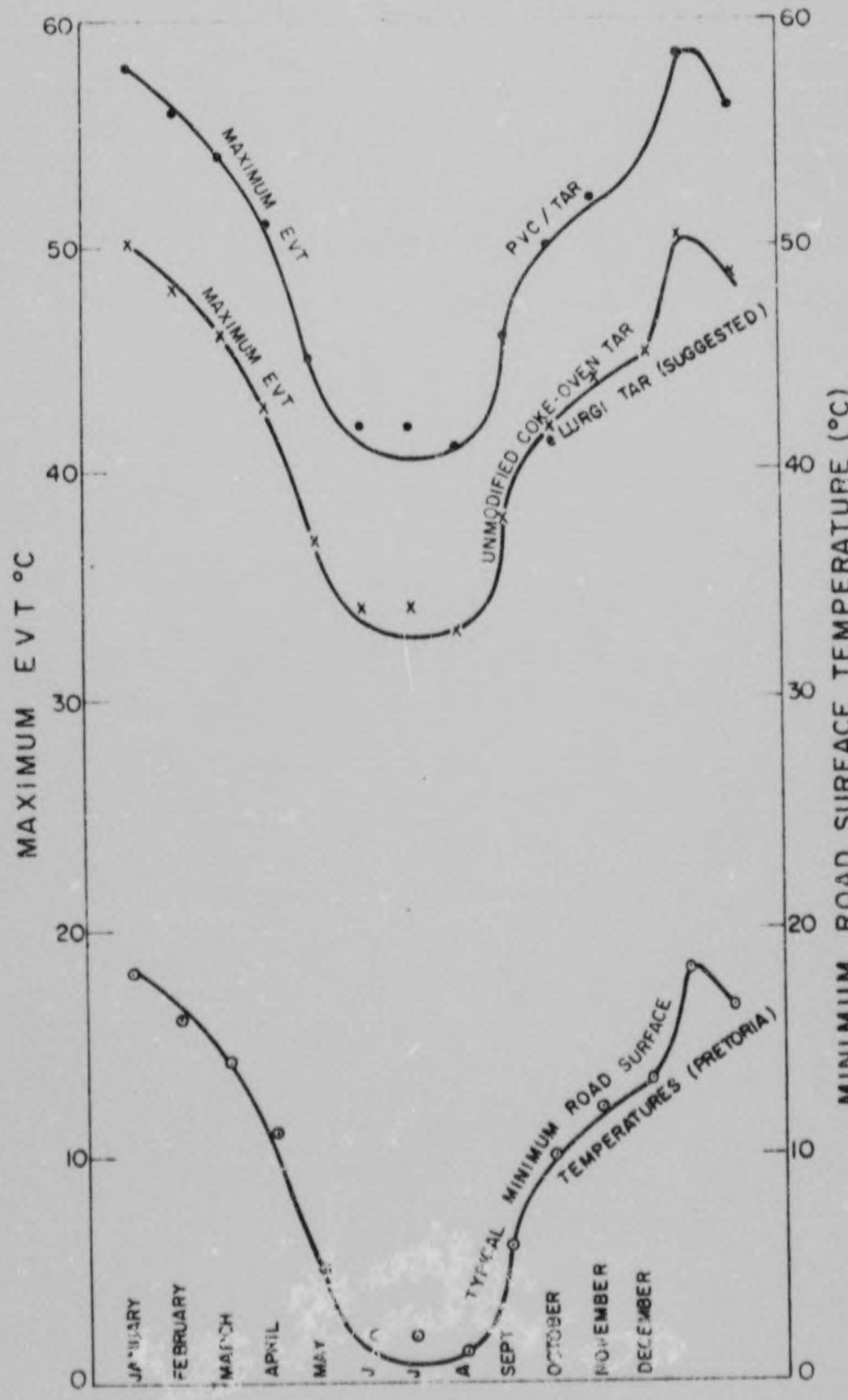

FIGURE 3-20

RECOMMENDED MAXIMUM EVTS FOR TARS THROUGHOUT THE YEAR, FOR THE PRETORIA REGION AND MINIMUM ROAD SURFACE TEMPERATURES (TYPICAL VALUES 1966).

grade than normal may be appropriate. However, for surface treatments this should not exceed 55°C Evt.

3.1.6.3 Storage and spraying

Although PVC/tar has been applied successfully by contractors, it is recommended that it be supplied to the site and sprayed by the manufacturer. Care should be taken to ensure that the temperature is kept below 110°C if storage for periods of up to 96 hours is necessary, and below 100°C where storage for longer periods is required. The binder should be raised to spraying temperature only immediately prior to spraying. Because of the danger of thermal degradation of the polymer, it is particularly important that localised overheating be minimised during the warm-up of PVC/tar in the tanker, and in particular the binder must be circulated whenever the heaters are used. For slotted nozzles, spraying temperatures and other conditions are as for unmodified tars. For nozzles of the whirling-jet type, it has been found that a ten per cent increase in speed is necessary to give a spread equivalent to that of unmodified tars (Kuhnel, 1970). In Highveld winter conditions the spraying period should be restricted to between 10 h 00 and 15 h 00, even for low-Evt tars.

3.1.6.4 Determination of the optimum binder application

Over the years numerous methods have been suggested for the design of surface treatments. Most of these are based on the work of Hanson (1934 - 1935) and the measurement of the Average Least Dimension (ALD) of the stone.

The simple procedure proposed here is based on the design method for single-seals in new constructions described in Technical Recommendations for Highways (TRH) No.3 (National Institute for Road Research, 1971). This was developed in the belief that in South Africa many, if not most reseals are designed without recourse either to assessments of stone embedment or purposeful measurements of the surface texture depth of the type described by Marais (1969) and other workers (Greyling, 1974). In the proposed procedure the more detailed methods of these authorities have been rationalised so as to take these effects into account without making any actual measurements. All that is required is a knowledge of the traffic population and pattern, the ALD of the stone and a classification of the existing surface from visual assessments.

As previously mentioned, when using tar and PVC/tar in single reseals only one stone size, 13,2 mm, is recommended and the first step is to **determine** the rate of application of the stone. This can be determined from the ALD, as shown in Figure 3 - 21a. The cold residual binder application can then be obtained using Figure 3 - 21b. In this case the traffic volume count should be corrected by adding 20 vehicles for every heavy vehicle and applying an eight per cent per annum growth factor from the date of the last count (as recommended by Greyling, 1974).

The cold residual binder application is converted to hot by making the necessary allowance for volume changes. Allowance is customarily made here for the expected decrease in volume which results from the loss of volatiles in the first year on the road. This reduction in volume may partially offset the beneficial effect of stone embedment and stone interlock. The measurements described in Part 2, Chapter 5 have shown that in the first twelve months volatile losses range from 10 per cent for the low Evt grades to 5 per cent for the high Evt grades.

The combined factors (Jamieson, 1974b) recommended for the various grades are:

35 - 40°C Evt - 1,17
40 - 45°C Evt - 1,16
45 - 50°C Evt - 1,13
50 - 55°C Evt - 1,11

A factor is then applied to allow for the condition of the surface to be sealed. From visual assessment the surface is placed in one of the following categories:

(1)	Very smooth, binder-rich surfacing	factor 0,95
(2)	Old slurry or lean seal or carpet with only small surface texture depth	factor 1,00
(3)	Lean surface treatment with moderate surface texture depth	factor 1,05
(4)	Lean surface treatment, 13,2 mm stone size, with high surface texture depth	factor 1,10

As described in TRH 3 an allowance should be made for the following

Absorption of binder by the stone If the stone, used uncoated, is very absorptive (e.g. binder absorption of above 1,0 per cent), the binder application should be increased by 10 per cent.

Climatic area The procedure is suitable for the Highveld area and the Cape Province coastal belt. For the Transvaal Lowveld and Natal coastal regions, with very hot summers and mild winters, reduce the

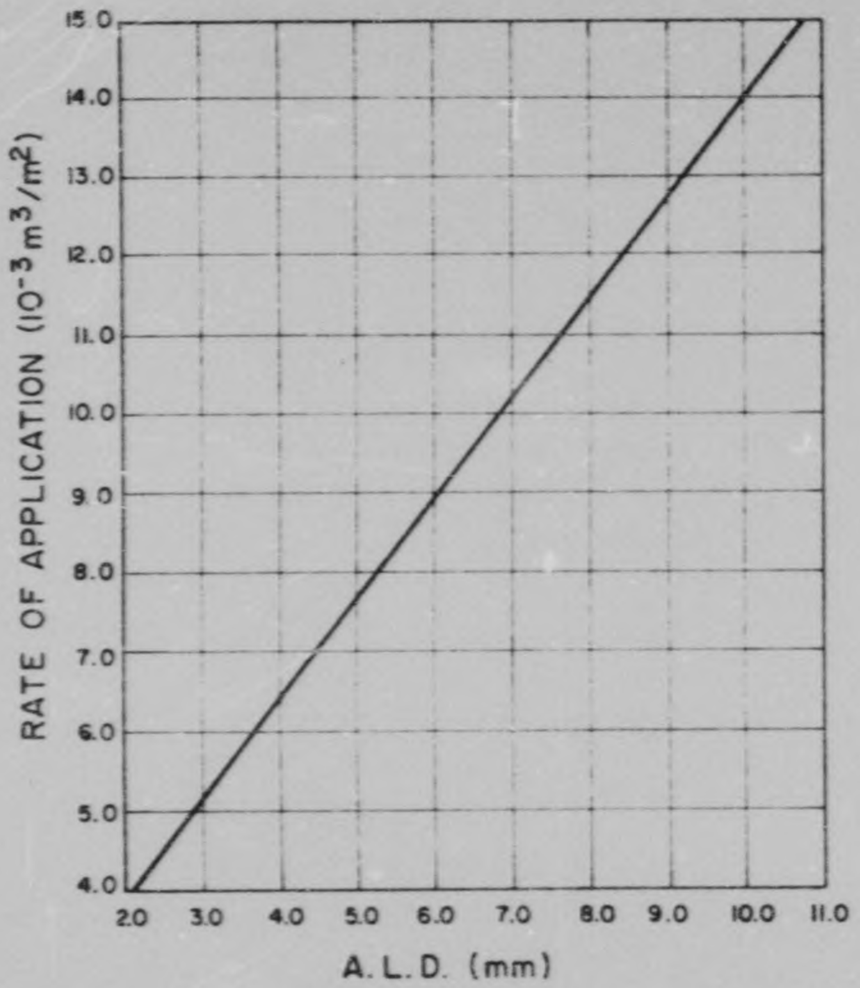

FIGURE 3-21(a)

APPLICATION OF STONE RELATED TO ITS AVERAGE LEAST DIMENSION (A.L.D)
(Reproduced from TRH3)

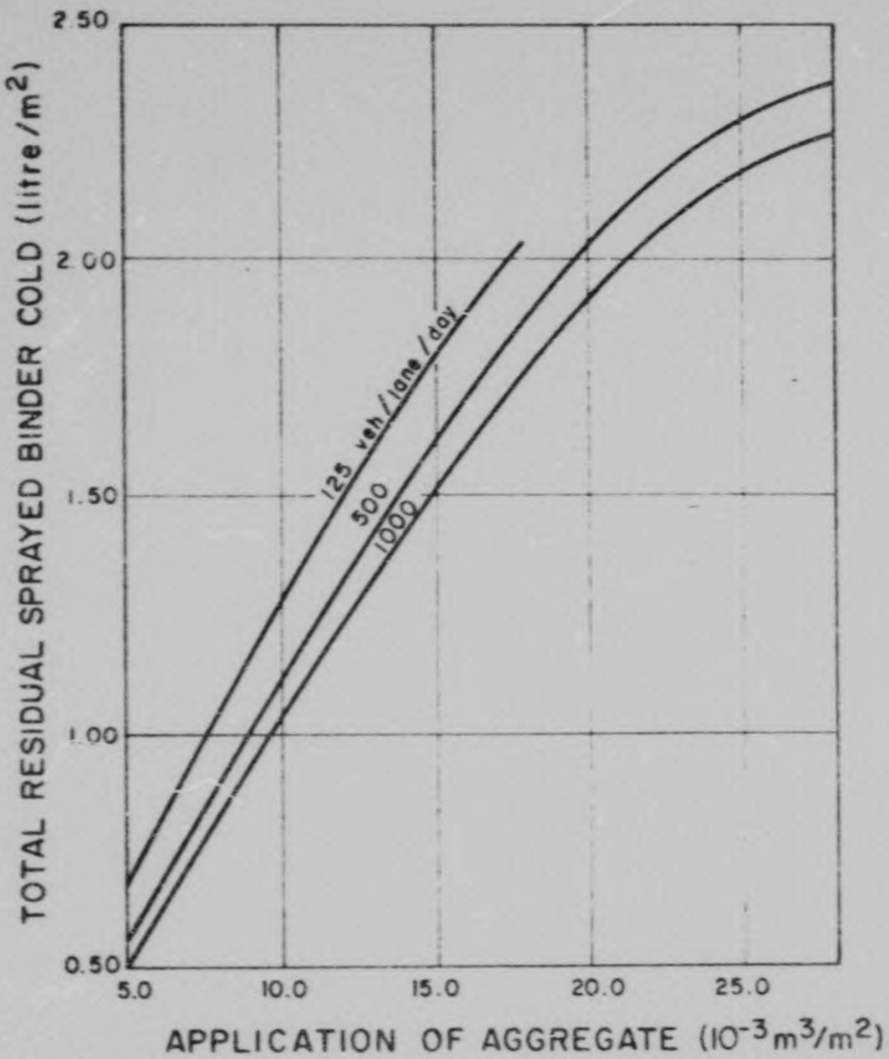

FIGURE 3-21(b)

APPLICATION OF BINDER FOR SINGLE-SURFACE TREATMENTS
(Reproduced from TRH3)

application of binder by 5 per cent maximum.

Steep inclines The application on the upgrade should be reduced by 10 per cent.

Urban areas and country towns. The application should be reduced by 10 per cent.

Proportion of heavy vehicles Where the percentage of heavy vehicles is greater than 20, the rate of application should be decreased by up to 10 per cent.

Where such corrections are made for more than one factor, in no case should the total reduction exceed 20 per cent.

3.1.6.5 Stone application

The amount of stone used is critical. While adequate (shoulder to shoulder) cover is essential, the use of excess stone will negate the advantage of PVC/tar as far as reducing the potential damage to windscreens is concerned. Provided that the new surface has been rolled and provided that chippings in contact with the binder film are not turned over, a light drag broom may be used to remove excess stone.

3.1.6.6 Opening to traffic

It has been mentioned that PVC/tar has an initial grip on the stone, which is superior to that achieved by other binders. However, because optimum wetting and adhesion takes some time to develop, it is recommended that traffic control be instituted immediately after rolling.

It is only necessary to stream the traffic to suit the work in progress (resurfacing is normally done lane by lane). This can be done by stop/go controls at either end of the construction. After a period of one hour both lanes may be opened to normal traffic conditions. If the work has been carried out correctly there is little danger of windscreen damage.

3.2 MODIFICATION WITH BITUMEN

N.B. It is emphasised that the locally produced tar/bitumen blends used in this study were experimental and were not necessarily representative of commercial production.

Resumé

The development of tar/bitumen blends is outlined.

The properties of samples of commercial blends used in Europe and of experimental blends prepared by South African manufacturers are examined.

It seems possible that these blends will have good service lives in surface treatments in South Africa. The samples of the European blends were used in small-scale surface treatment sections and these are still satisfactory after six years in service. Monitoring tests show that the source of the tar is an important factor determining its weathering rate but this may be controlled by suitable selection of the oils used in the tar component.

From fundamental principles, four viscosity grades have been recommended for South African conditions. Various tests for controlling the quality are discussed, and specification requirements are proposed together with suitable spraying temperature ranges for each grade.

It has long been realised that by blending together tar and bitumen, road binders could be produced which would have the advantages of each component, i.e. the superior weathering resistance and rheological properties of bitumen and the superior wetting and anti-stripping characteristics of tar. A study of the literature reveals that the commercial production of such blends has been attempted for many years (Road Research Laboratory, 1948), but it is only in the last fifteen years that satisfactory blends of about equal proportions of tar and bitumen have been determined (Wood, 1966 and McNeil, 1970b). Although most of the developments have taken place in Europe, it is worth recording that as long ago as 1936 the feasibility of blending local gas-works tar from the Johannesburg Municipal gas works with bitumen and natural lake asphalt was considered (Selvey, 1936).

In Britain the availability of tars has declined since natural (North Sea) gas has been utilised, but in recent years the usage of tar/bitumen blends has increased to the extent that now they comprise thirty per cent of all binders employed in surface treatments. This shows that in that country there is a need for surface treatment binders to have adequate adhesion characteristics.

In general, in South Africa's warm dry climate, adhesion problems are less serious than in Europe, although such difficulties are sometimes severe in coastal regions. The economic benefits in reducing this country's usage of road bitumen have been explained and the main purpose of the development of tar/bitumen blends in this country is to improve the durability and rheological properties of the local tars. Such binders would be expected to have a slight price advantage over petroleum bitumen in areas close to sources of tar but this would depend upon the proportion of tar in the blends.

While they may ultimately be used in hot-mix surface courses the first objective in South Africa has been to develop tar-bitumen blends for surface treatments. Blends of Lurgi tar and bitumen are particularly important for, as has been shown, Lurgi tar is slightly less durable than coke-oven tar and it is not compatible with PVC

3.2.1 Development of tar/bitumen blends

One important distinction that may be made between the blends of former times and those that are produced today is the proportion of tar and bitumen used. Formerly there were limitations to the proportions in which tar and bitumen could be combined, and when one or other component exceeded about 25 per cent a resinous precipitate or sludge was formed. In recent years this technical problem has been overcome and it is asserted that the manufacture of blends comprising virtually equal proportions of tar and bitumen is straightforward and that storage conditions are less critical than is the case with PVC/tars. The performance of tar/bitumen blends in a variety of applications appears to give satisfaction (International Road Tar Conference, 1974). These blends are used in Holland, France, West Germany, Belgium, Switzerland and the United Kingdom.

In Britain blends may be on the tar-rich side and proposed specifications stipulate that tar contents may vary from 30 - 55 per cent and bitumen contents may range from 45 - 70 per cent (Department of the Environment, 1972). In France and Switzerland blends are known either as bitumen/tars, in which the major constituent is bitumen, or as fluxed bitumens, in which the bitumen is fluxed with tar-oils (tar/bitumen blends, which are tar-rich). In Germany blends are bitumen-rich (70 - 75 per cent).

At this point the author wishes to make a clear distinction between "pitch/bitumen" and "tar/bitumen" blends. Pitch/bitumen blends have no light or medium tar-oils added and were developed in Britain for use in dense surfacing mixtures carrying heavy traffic loads, in which the pitch was usually obtained from a vertical-retort source. Pitches of either 50 or 80°C softening point (ring and ball) were used. The ideal was that the more rapid weathering of the pitch would promote a continuous erosion of the binder at the road surface, and so counter the tendency for the binder to form a film over the stone on the surface, thus maintaining adequate skid resistance properties. Tar/bitumen blends contain significant amounts of tar oils and are of a lower viscosity than pitch/bitumens. Although they are used in wearing courses and basecourses (Liversedge and Bullock, 1972) their primary use is in surface treatments (Wood, 1966).

3.2.2 Compatibility of tar and bitumen

In Part 2, Chapter 2.2. it was determined that coal tars are variable in composition depending on their origin and, in particular some have a high paraffinic content whereas others are predominantly aromatic. These factors have a strong bearing on the ease with which tars can be blended with bitumens.

McNeil, (1970b) showed that mixtures of coke-oven tar (42°C Evt) and 200 Pen. petroleum bitumen were incompatible within blend proportions of 25 - 75 per cent*. These results are reproduced in Table 3 - 18

When identical viscosity grades were used low-temperature tar and bitumen were compatible in all proportions as ashown in Table 3 - 19.

In the earlier South African work, Selvey (1936) found that vertical-retort tar could be mixed in any proportion with natural lake asphalts from Trinidad, Iraq and Cuba. Some separation, "demixtion" at high viscosities was noted and though the author claimed that the blend could be re-homogenised by raising the temperature until the viscosity was less than 50 seconds (STV), no mention was made of the consequences of "demixtion" occurring in service at low road temperatures.

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* This would appear to put bitumens from Middle East crudes (which are used by South African refineries) at a disadvantage for this purpose as these are typically paraffinic in character and moderate in asphaltene content.

TABLE 3 - 18

THE COMPATIBILITY AND RHEOLOGICAL PROPERTIES OF BLENDS OF 42°C EVT COKE-OVEN ROAD TAR AND 200 PEN. BITUMEN (FROM McNEIL, 1970b)

Composition wt. per cent Tar	Bitumen	Evt (°C)	Brittle Pt °C	Evt-brittle pt. °C	Condition
100	0	42,9	-21	63,9	Homogeneous
91,6	8,4	45,0	-21,6	66,6	Homogeneous
83,2	16,8	44,8	-17,9	62,7	Homogeneous
74,8	25,2	42,8	-13,1	55,9	Border line
66,4	33,6	40,5	-30,7	71,2	Two phases
58,0	42,0	-	-	-	Two phases
49,6	50,4	36,0	-35,5	71,6	Border line
41,2	58,8	40,8	< -35,0	> 75,8	Border line
32,8	67,2	41,1	-30,7	71,8	Homogeneous
24,4	75,6	42,5	-31,2	73,7	Homogeneous
16,0	84,0	42,6	<-35	> 77,6	Homogeneous

TABLE 3 - 19

THE COMPATIBILITY AND RHEOLOGICAL PROPERTIES OF BLENDS PREPARED FROM LOW TEMPERATURE CRUDES AND 200 PEN. BITUMEN (FROM McNEIL, 1970b)

Composition wt. per cent Tar	Bitumen	Evt (°C)	Brittle pt. °C	Evt-brittle pt. °C	Condition
100	0	42,4	-15,7	58,1	Homogeneous
92,5	7,5	44,8	-14,3	59,1	Homogeneous
84,6	15,4	42,1	-12,1	54,2	Homogeneous
76,9	23,1	41,9	- 7,7	49,6	Homogeneous
69,2	30,8	43,4	-30,2	63,6	Homogeneous
61,5	38,5	42,6	-30,3	72,9	Homogeneous
53,8	46,2	40,9	-30,2	71,1	Homogeneous
46,1	53,9	42,4	-30,9	73,3	Homogeneous
38,4	61,6	41,9	-32,0	73,9	Homogeneous
30,7	69,3	42,0	-30,5	72,5	Homogeneous
25,0	77,0	41,7	-32,0	73,7	Homogeneous

Author Jamieson Ian Laurence
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1977

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