DEVELOPMENT OF A PRACTICAL FIELD METHOD FOR THE DETERMINATION OF THE ELASTIC RECOVERY OF MODIFIED BINDERS

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Abstract

Elastic recovery of a binder is one of the properties which is used to control the quality of the binder in road construction. The laboratory equipment used to determine elastic recovery is generally too expensive and bulky for standard usage in field laboratories. The field elastic recovery test (FERT), based on the standard laboratory ductilometer test, was designed to overcome this problem. In this paper, the design and development of FERT, its repeatability and reproducibility, its sensitivity to changes in testing conditions and finally its correlation with the standard laboratory ductilometer test are addressed. Results of tests conducted using the FERT were found to have acceptable repeatability and reproducibility, low sensitivity to changes in testing conditions and a one-to-one relationship with the results of elastic recovery tests conducted using the standard laboratory ductilometer.

1. INTRODUCTION

Over the last few years there has been an increase in traffic loading on our roads, coupled with an increase in the heavy vehicle component of the traffic and an increase in tyre pressures. This has resulted in the road surface being subjected to significantly higher contact stresses, the rapid deterioration of the road network and increased distress in the form of cracking and deformation. Added to this is the problem that funds available for maintenance are limited.

There is therefore a growing need for the increased cost effective utilization of our limited resources. This implies an increased use of modified binders, with their enhanced properties such as increased elasticity and recovery properties, to increase the resistance of our roads to deformation and fatigue and to improve their durability.

For the benefits of using modified binders to be completely realised, there should be a high standard of quality control on site. Control testing of bituminous binders during construction is important to ensure the optimum performance of the product. This is even more essential in the changing environment in South Africa, where first world technology is being implemented in developing communities and where labour-enhanced construction methods are used.

Certain very important properties of binders can usually only be tested in established laboratories and with equipment which is too expensive and bulky for general use in field laboratories. The measurement of the elastic recovery of a binder is one such property, which, together with low temperature ductility, is used to ensure the correct chemical balance and homogeneity of the modified binder by measuring the binder's internal cohesion and its elastic recovery properties.

Ductility tests require a large ductility bath, while the elastic recovery test can be performed in a considerably smaller water bath which can be used in field laboratories. As the apparatus is relatively small, the elastic recovery test can be used in field laboratories for determining the suitability of modified binders.

This paper details the design and development of the Field Elastic Recovery Test (FERT) which was conducted on behalf of the Department of Transport (Airey, 1). A number of different binders were tested using the FERT and the sensitivity of these results to changes in test conditions was investigated. The elastic recovery results were then correlated with those obtained from the standard laboratory ductilometer. The correlation between the standard laboratory test and the field laboratory test is necessary because the FERT elastic recovery results will be used to determine whether the elasticity of the binder tested falls within specified limits.

2. DESIGN AND DEVELOPMENT OF THE FIELD ELASTIC RECOVERY TEST (FERT)

2.1 Design of the field elastic recovery test (FERT) apparatus

The apparatus used for the field elastic recovery test (FERT) is based entirely on the ductilometer used for the standard laboratory ductility and elastic recovery tests. The elastic recovery test procedure (ASTM, 2) is represented graphically in Figure 1.

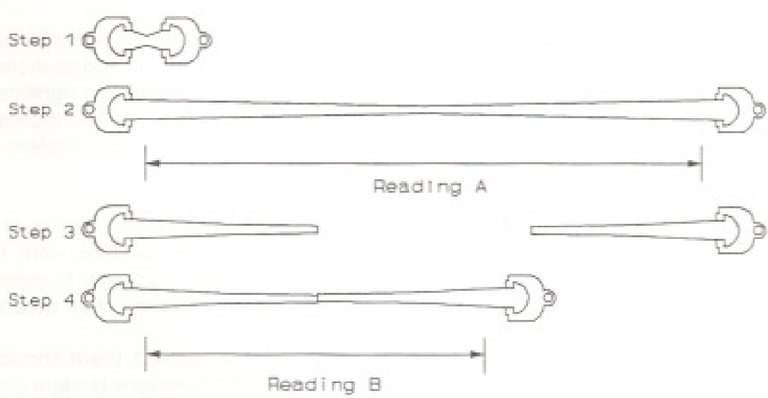

Figure 1: Elastic recovery test

The FERT apparatus has five main parts, namely the water bath, the guide rods, the testing components, the pulley system and the driving mechanism. The top, side and end views of the FERT apparatus can be seen in Figures 2, 3 and 4.

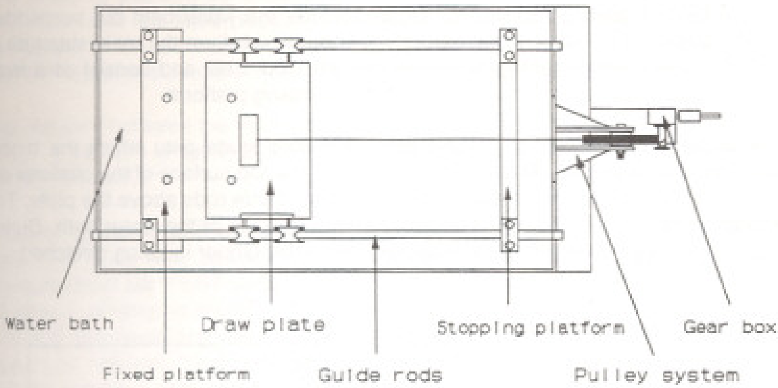

Figure 2: FERT apparatus - top view

Stainless steel or aluminium 2 mm thick plates are welded together to form a water bath, 530 mm by 300 mm with a depth of 100 mm. The water bath is supported by angle iron bars welded together to form a cradle, their flanges forming a narrow ledge and side support into which the water bath is placed. This angle iron cradle is positioned on top of four angle iron legs which are strengthened with cross bracing. The outside of the water bath is insulated with polystyrene to help maintain the temperature within the water bath.

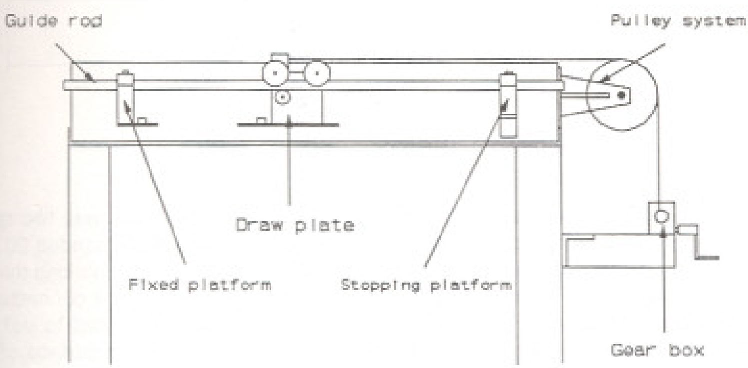

Figure 3: FERT apparatus - side view

There are two steel guide rods (12 mm ϕ) running the length of the water bath. These steel rods are symmetrically positioned on either side of the water bath and welded 70 mm above the base of the water bath and 220 mm apart.

There are three testing components, situated inside the water bath but suspended above the base of the bath by the steel guide rods, which form the main structure of the FERT. These components are all made from mild steel and consist of a fixed platform, a moving platform (draw plate) and a stopping platform.

The fixed platform consists of a base plate with two studs onto which the binder sample moulds are placed. At the back end and on the top surface of the platform are two columns that connect the base plate to the steel guide rods above the plate. The base plate is therefore suspended 20 mm above the base of the water bath. During the test the fixed platform remains stationary while the binder is being stretched.

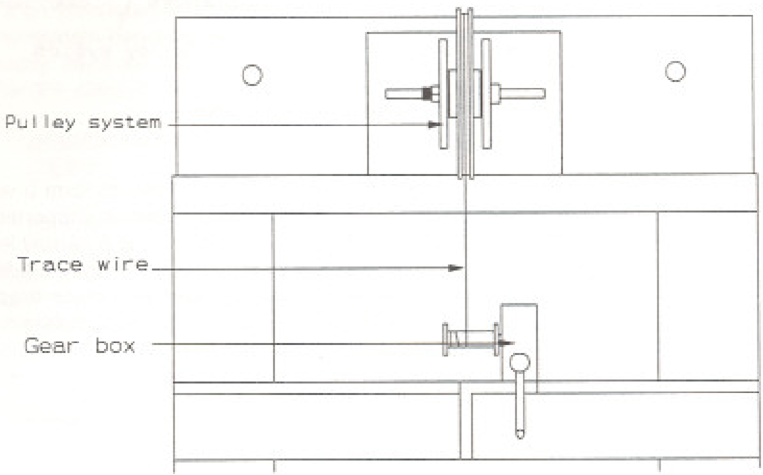

Figure 4: FERT apparatus - end view

The moving platform, like the fixed platform, consists of a base plate with two studs onto which the sample moulds can be placed. The base plate is suspended 20 mm above the floor of the water bath by two sets of rollers (wheels) that run along the top of the steel guide rods. The axles of the rollers are attached to columns connected to the top surface of the base plate. The ±41 kg stress trace wire, used to pull the platform along, is attached to a central column welded onto the top surface of the base plate.

The moving platform is pulled forward by the trace wire which is attached to the driving mechanism. A set of wheels under the guide rods prevents the draw plate from rotating, while the upper two sets of wheels have outside flanges to prevent the draw plate from twisting during testing.

The stopping platform consists of a base plate with a solid block attached to its underside. Like the fixed platform there are two columns attached to the top of the base plate which are fastened to the steel guide rods. During the test the stopping platform remains stationary while the moving platform is pulled towards it.

The distance between the front edge of the moving platform and the back edge of the stopping platform is set at 200 mm, which is the maximum elongation allowed for in the test method.

A pulley system is welded at the stopping platform end to the outside of the water bath. The trace wire passes over the pulley system before reaching the driving mechanism of the FERT apparatus. The wheel of the pulley has been divided into 10 mm arc lengths as shown in Figure 5. The arc lengths are given from 0 to 200 mm with their corresponding times needed to pull the draw plate at the required elongation rate of 50 mm/min. The elongation times on the pulley wheel are used to aid the manual operation of the FERT apparatus.

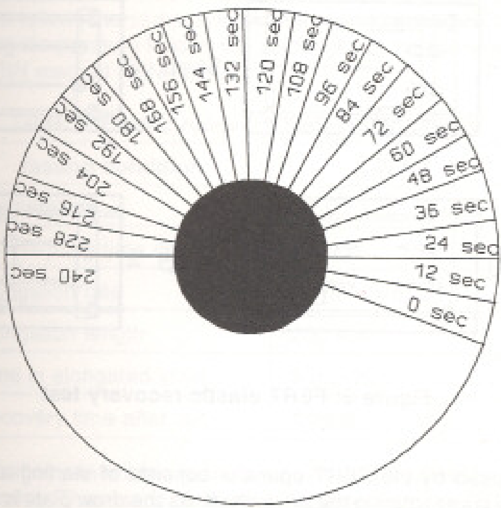

Figure 5: Elongation time

The driving mechanism of the FERT apparatus consists of a manually driven 50:1 gear box connected by means of a bracket to the stand. The driving shaft is turned by the FERT operator, which results in the driven shaft rotating at a ratio of 1 rotation to the 50 rotations of the drive shaft. The trace wire used to pull the draw plate is wound around the reel on the driven shaft. This action leads to the draw plate being pulled through its elongation distance of 200 mm.

2.2 Operation of the field elastic recovery test

The same equipment and procedures are used in the preparation of the binder prior to testing using the FERT as for the laboratory elastic recovery test (ASTM, 2).

The field elastic recovery test is used to measure the elastic recovery of bituminous binders, mainly modified binders. The testing procedure is identical to that used for the standard laboratory elastic recovery test using the ductilometer (ASTM, 2). By adding ice to the water, the temperature of the water bath is kept at 10°C. The testing procedure is graphically presented in Figure 6.

The binder sample is stretched by means of a manually driven elongation system which provides a relatively constant elongation rate similar to that used in the laboratory test. The elongation rate for the FERT should be as close as possible to the ductilometer rate of 50 mm per minute (50 mm/min), which means an elongation time of 4 minutes for the 200 mm deflection. The use of the 50:1 ratio gear box and the marked elongation lengths and times on the pulley wheel, help the FERT operator to produce the 200 mm elongation at the required rate of 50 mm/min.

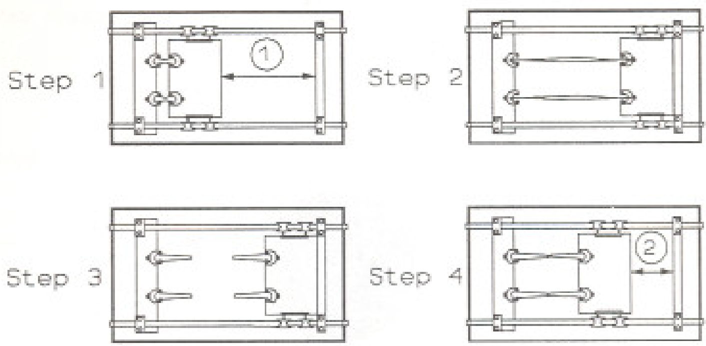

Figure 6: FERT elastic recovery test

The procedure used by the FERT operator consists of starting a stop watch at the same time as he starts rotating the drive shaft. As the draw plate is pulled forward, the pulley wheel will start to rotate. The operator therefore simply alters his rotational speed on the drive shaft so that the time on the stop watch corresponds to the times marked on the rotating pulley wheel as each of these time divisions reach a specific reference point. The use of a stop watch and the elongation times on the pulley wheel should result in the operator being able to produce the 200 mm elongation within a time range of 10 seconds either side of the required 240 seconds. This corresponds to an elongation range of 48 mm/min to 52 mm/min, which is only a 4 percent error.

The FERT elastic recovery of the binder specimens can be calculated using Equation 1.

$$\% \text{ Recovery} = \frac{\text{Reading 2}}{\text{Reading 1}} \times 100 \quad \text{(Eq.1)}$$

3. ELASTIC RECOVERY TESTING WITH THE FIELD ELASTIC RECOVERY TEST (FERT)

This section serves to illustrate the principles of the field elastic recovery test (FERT) and the effects of changing test conditions on the results. The repeatability and reproducibility (TMH 5, 3) of the elastic recovery results obtained from the FERT apparatus as well as the sensitivity of these results to changes in the testing conditions are investigated. A good repeatability and reproducibility of the elastic recovery results is essential for confident use of the FERT.

3.1 Repeatability

A set of elastic recovery tests was performed under the prescribed conditions suggested by the South African Modified Binders Committee and given in Table 1. The sample preparation follows the same procedure as used for the ASTM test (ASTM, 2), although the testing temperature follows the guidelines of the low temperature ductility test given in the DIN method (DIN, 4).

Table 1: Elastic recovery testing conditions

Testing condition	Value
Temperature	10°C
Conditioning time @ 10°C	2 hours
Elongation rate	50 mm/min
Elongation length	200 mm
Time in elongated state	5 minutes
Recovery time after cut	1 hour

A number of unmodified penetration grade bitumens and modified binders were tested in the FERT apparatus. The elastic recoveries obtained from the FERT are presented in Table 2.

Since the number of tests performed on each binder is not the same, the range rather than the standard deviation of the results is used to determine the repeatability of the elastic recovery results.

A difference of 2 mm or 1 percent between results is acceptable because of the practical difficulties in placing the cut ends together without distorting the binder or leaving a small gap between the ends. This 1 percent error will also be present in the standard laboratory test. Further errors, related to variations in the binders, will also be present. Allowing for these additional errors, a 5 percent error can be assumed to be an acceptable limit.

In Table 2 it can be seen that the repeatability of the elastic recovery results is acceptable, the ranges for the different binders being below the 5 percent acceptable limit.

Table 2: FERT elastic recovery percentages under standard testing conditions

Test number	Binders						
	60/70 pen	80/100 pen	Bit-Rubber	EVA	SBR	SBS (60/70)	SBS (80/100)
1	3,5	12,0	88,5	56,0	61,5	62,0	61,5
2	4,0	12,5	89,5	55,5	60,0	62,5	61,5
3	5,0	12,5	89,0	57,5	62,5	62,5	61,5
4	5,0	12,0	88,5	57,0	63,5	62,0	60,5
5				57,5	61,5		61,5
6				57,0	62,0		61,5
Average	4,4	12,3	88,9	56,8	61,8	62,3	61,3
Std dev.	0,75	0,29	0,48	0,82	1,17	0,29	0,41
Range	1,5	0,5	1,0	2,0	3,5	0,5	1,0

3.2 Sensitivity of the field elastic recovery test

Slight variations in some of the testing conditions can be expected, as the FERT is to a large extent operator-dependent. Understanding the effects of these variations on the test results is important if the FERT is to be able to fulfil its role as a practical field elastic recovery test method.

The elongation rate and the testing temperature are considered areas of possible variation owing to the fact that they are operator-dependent. These two factors, as well as the pre-testing conditioning time, were varied to enable their effects on the test results, to be evaluated.

3.2.1 Varying elongation rates

Three different elongation rates were used during the stretching phase of the elastic recovery test. The standard rate of stretching the binder through 200 mm in four minutes (50 mm/min) was used as well as a lower and higher rate of 5 minutes (40 mm/min) and 3 minutes (67 mm/min).

The higher and lower rates are both extreme cases. The FERT operator should be able to maintain the elongation rate between 48 and 52 mm/min as described in Section 3.2. The rest of the testing conditions were the same as for the standard elastic recovery test used in Section 3.1.

Only two tests were performed at the higher and lower elongation rates, since the repeatability of the FERT was very good as shown in Section 3.1. The elastic recovery results are given in Table 3, where the range for the tests falls within the acceptable limit of 5 percent for all 5 binders and 3 elongation rates. The elastic recoveries at the different elongation rates are shown in Figure 7.

The similarity of the elastic recovery results obtained from the three elongation rates, for each particular binder, is determined by calculating the difference between the average elastic recovery obtained using the standard test conditions and the average result using the quicker or slower elongation rates. The similarity standards are the same as the repeatability standards with an acceptable limit being set at a difference of 5 percent.

Table 3: FERT elastic recovery percentages at different elongation rates

Test number	Binders														
	80/100 pen			EVA			SBR			SBS (60/70)			SBS (80/100)		
	Time to stretch binder through 200 mm (minutes)														
	5	4	3	5	4	3	5	4	3	5	4	3	5	4	3
1	13.0	12.0	12.5	57.5	56.0	57.5	60.0	61.5	62.5	60.0	62.0	62.0	60.0	61.5	61.5
2	12.5	12.5	12.0	57.5	55.5	57.0	63.0	60.0	60.5	61.0	62.5	61.5	61.0	61.5	61.0
3		12.5			57.5			62.5			62.5			61.5	
4		12.0			57.0			63.5			62.0			60.5	
5					57.5			61.5						61.5	
6					57.0			62.0						61.5	
Average	12.8	12.3	12.3	57.5	56.8	57.3	61.5	61.8	61.5	60.5	62.3	61.8	60.5	61.3	61.3
Std dev.	0.35	0.29	0.35	0.0	0.82	0.35	2.12	1.17	1.41	0.71	0.29	0.35	0.71	0.41	0.35
Range	0.5	0.5	0.5	0.0	2.0	0.5	3.0	3.5	2.0	1.0	0.5	0.5	1.0	1.0	0.5
Difference	0.5		0.0	0.8		0.5	0.3		0.3	1.8		0.5	0.8		0.0

In Table 3 and Figure 7 it can be seen that the difference between the average elastic recovery obtained using the standard test conditions and the average result using the quicker or slower elongation rates are well within the acceptable 5 percent similarity limit.

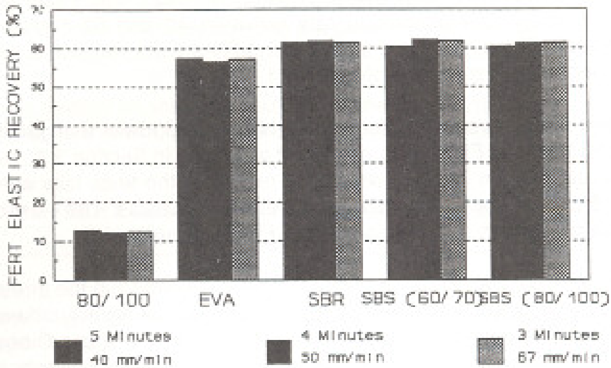

Figure 7: FERT elastic recoveries at different elongation rates

This means that changing the first testing condition likely to vary during field operation, i.e. the elongation rate, will have no significant influence on the elastic recovery results of the binders being tested. One possible reason for the low sensitivity of the test results to the different elongation rates is that the binders all remain in their stretched state for 5 minutes after being stretched. The significance of the elongation rate therefore seems to be reduced by the binder remaining in its stretched state for 5 minutes prior to being cut. It is much easier to control the standard 5 minute time in the elongated state, than the rate of elongation needed to stretch the binder.

The small variations in the elongation rate envisioned during the field operation of the FERT apparatus should therefore not effect the elastic recovery results or their repeatability.

3.2.2 Different conditioning times

The second condition that could possibly vary in the field elastic recovery test is the conditioning time of 2 hours prior to stretching the binder. Three conditioning times of 30 minutes, one hour and the standard two hours were used prior to the elongation phase of the test.

The reason for choosing the shorter conditioning times was to determine the possibility of shortening the FERT procedure. The rest of the testing conditions were the same as for the standard elastic recovery test as used in Section 4.1. The elastic recovery results are given in Figure 8 and Table 4, where the range for the tests falls within the acceptable limit of 5 percent for all 5 binders and 3 conditioning times.

In Table 4 and Figure 8 it can be seen that, for the two penetration grade bitumens and the two elastomer-modified binders, the similarity between the shorter conditioned samples and the 2- hour conditioned samples is within the acceptable 5 percent error limit. The one hour conditioning period's elastic recovery generally has a greater similarity to that of the standard 2-hour conditioning period's elastic recovery, compared to that of the 30-minute conditioning period.

Table 4: FERT elastic recovery percentages after different conditioning times

Test number	Binders														
	60/70			80/100			EVA			SBR			SBS (80/100)		
	Conditioning time prior to stretching (hours)														
	½	1	2	½	1	2	½	1	2	½	1	2	½	1	2
1	4.0	5.0	3.5	12.0	13.0	12.0	49.5	52.5	56.0	62.0	63.0	61.5	60.0	60.5	61.5
2	4.5	4.5	4.0	11.5	12.5	12.5	49.5	51.5	55.5	60.0	60.5	60.0	60.0	60.5	61.5
3			5.0			12.5	44.5	53.5	57.5		61.5	62.5			61.5
4			5.0			12.0	44.5	54.0	57.0			63.5			60.5
5									57.5			61.5			61.5
6									57.0			62.0			61.5
Average	4.3	4.8	4.4	11.8	12.8	12.3	47.0	52.9	56.8	61.0	61.7	61.8	60.0	60.5	61.3
Std dev.	0.35	0.35	0.75	0.35	0.35	0.29	2.89	1.11	0.82	1.41	1.26	1.17	0.0	0.0	0.41
Range	0.5	0.5	1.5	0.5	0.5	0.5	5.0	2.5	2.0	2.0	2.5	3.5	0.0	0.0	1.0
Difference	0.13	0.38		0.5	0.5		9.75	3.88		0.83	0.17		1.33	0.83	

However, for the EVA-modified binder, the deviation from the standard test, after 30 minutes of conditioning, falls outside the 5 percent acceptable difference. The average elastic recovery for the 1-hour conditioning period is still within the 5 percent acceptable difference compared to the results after the standard 2-hour conditioning period.

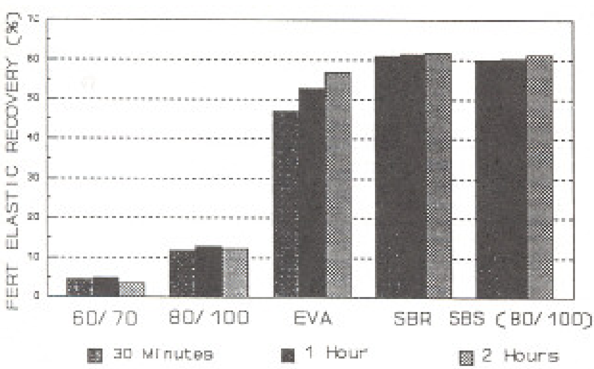

Figure 8: FERT elastic recoveries after different conditioning times

The shortening of the conditioning time therefore seems to have a slight effect on the elastic recovery of certain binders tested in the FERT apparatus. Not all the binders tested showed a significant change in elastic recovery with the decrease in conditioning time, thereby suggesting that the conditioning time may be shortened but should not be less than one hour.

3.2.3 Different testing temperatures

Two testing temperatures were used during the field elastic recovery test. The first temperature was the standard test temperature of 10°C, while the second temperature was 50 percent higher at 15°C. The higher temperature was selected to be able to predict the possible changes that could be envisioned should the FERT operator allow the test temperature to increase above the standard 10°C temperature.

The elastic recovery results are presented in Table 5, where it can be seen that there is a decrease in the elastic recovery at the elevated temperature of the plastomeric EVA-modified binder. The elastomeric SBS-modified binder showed a different trend, with an increase in the elastic recovery at the higher temperature. The deviations from the standard test for the two binders fall within the 5 percent acceptable difference.

Large increases of approximately 5°C above the standard test temperature of 10°C are not foreseen, even though the FERT is operator-dependent. The range of temperature variations can be realistically limited to between 9°C to 12°C with moderately good operator vigilance during testing. This means that changes in the elastic recoveries will be even less than the deviations from the standard test found for the 15°C testing temperature. The slight changes in the testing temperature of 10°C should therefore not adversely effect the similarity of the resulting elastic recoveries compared to those obtained using the standard testing conditions.

Table 5: FERT elastic recovery percentages at different testing temperatures

Test number	Binders			
	EVA		SBS (80/100)	
	Test temperature (°C)			
	10°C	15°C	10°C	15°C
1	56,0	57,0	61,5	63,0
2	55,5	56,5	61,5	63,5
3	57,5	52,0	61,5	
4	57,0	50,0	60,5	
5	57,5		61,5	
6	57,0		61,5	
Average	56,8	53,9	61,3	63,3
Std dev.	0,82	3,42	0,41	0,25
Range	2,0	7,0	1,0	0,5
Difference		2,88		1,79

3.2.4 Multiple changes in test conditions

The combined effect of changes in the testing conditions on the elastic recoveries obtained from the FERT was investigated by simultaneously changing all three testing conditions considered likely to change during the FERT.

The elastic recovery results are presented in Table 6. In this Table it can be seen that, although the average elastic recovery obtained by using the changed testing conditions was greater than the elastic recovery obtained using the standard testing variables, it is still within the 5 percent acceptable limit.

The combined effect of changing the testing conditions expected possibly to change during the FERT, therefore still produces elastic recoveries which are very similar to the elastic recoveries obtained using the standard testing variables. Therefore the combined effect of changing the testing conditions has, in this experiment, no significant influence on the elastic recovery results obtained from the FERT.

It should be stressed that the selected conditions are all extreme values. Smaller deviations from the prescribed conditions (which are more likely) could possibly result in an even lower sensitivity of the test results.

Table 6: FERT elastic recovery percentages at simultaneous changes in testing conditions

Test number	Test variables	
	10°C	15°C
	2 hours	1 hour
	50 mm/min	40 mm/min
1	61,5	64,5
2	60,0	65,5
3	62,5	64
4	63,5	64,5
5	61,5	64
6	62,0	64,5
Average	61,8	64,3
Std dev.	1,17	0,68
Range	3,5	2,0
Difference		2,50

4. CORRELATION BETWEEN FIELD ELASTIC RECOVERY TEST (FERT) AND STANDARD LABORATORY DUCTILOMETER

This section contains the correlation of the FERT elastic recovery results with those obtained from the standard laboratory ductilometer. The standard elastic recovery test variables used in Section 3.1 and given in Table 1 were used for both the elastic recovery tests in the laboratory (ductilometer) and in the field (FERT apparatus).

The repeatability of the elastic recovery results was determined from the range of the results. The results can be considered acceptable if they are within the 5 percent acceptable limit. The elastic recovery results calculated for the different binders, tested using the FERT and the standard laboratory ductilometer, are given in Table 7.

The correlation or relationship between the ductilometer elastic recoveries and the FERT elastic recoveries can be established by looking at the similarity between the results obtained from the two tests. The similarity of the elastic recovery results obtained from the two tests, for each particular binder, are determined by calculating the difference between the average elastic recovery percentage obtained, using the ductilometer test, and the average result, using the FERT. In Table 7 it can be seen that the differences between the elastic recovery results obtained from the two methods are within the 5 percent acceptable error limit for all the binders.

Table 7: Ductilometer and FERT elastic recovery percentages

Test number	Binders											
	80/100 pen		Bit-Rubber		EVA		SBR		SBS (60/70)		SBS (80/100)	
	Testing apparatus											
	Duc.	FERT	Duc.	FERT	Duc.	FERT	Duc.	FERT	Duc.	FERT	Duc.	FERT
1	6.0	5.0	90,5	88,5	41,5	42,5	61,5	61,5	60,5	62,0	60,5	61,5
2	6.0	5.5	90,0	89,5	42,0	43,5	61,0	60,5	61,0	62,5	60,5	61,5
3		6.0		89,0	43,0	42,0		62,5		62,5		61,5
4		5.5		88,5		43,0		63,5		62,0		60,5
5								61,5				61,5
6								62,0				61,5
Average	6.0	5.5	90,3	88,9	42,2	42,8	61,3	61,8	60,8	62,3	60,5	61,3
Std dev.	0.0	0.41	0,35	0,48	0,76	0,65	0,35	1,17	0,35	0,29	0,0	0,41
Range	0,0	1,0	0,5	1,0	1,5	1,5	0,5	3,5	0,5	0,5	0,0	1,0
Difference		0,50		1,38		0,58		0,58		1,50		0,83

The elastic recoveries obtained from the FERT can be assumed to have a one-to-one correspondence with the elastic recoveries obtained from the standard laboratory ductilometer.

Figure 9 shows the correlation between the standard laboratory ductilometer test and the field elastic recovery test graphically. The correlation yielded an R-squared value of 0.985.

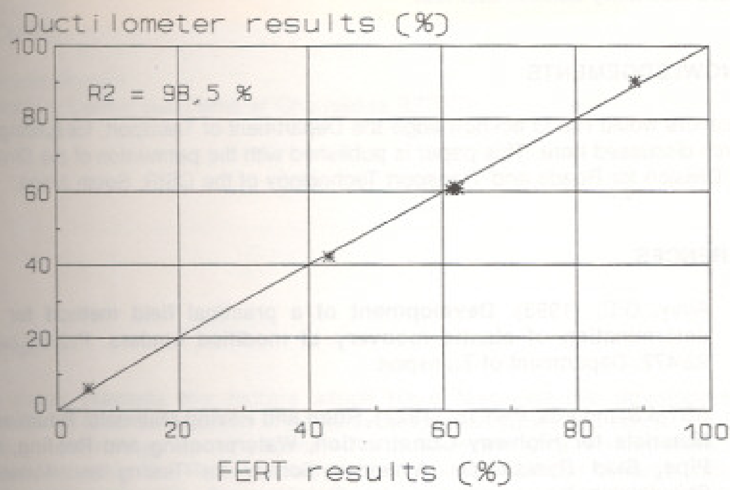

Figure 9: Correlation between FERT and standard laboratory ductilometer

Almost identical elastic recovery results for the two tests are expected since both tests were performed under the same standard testing variables and conditions. The slight variations in the elongation rate and the testing temperature expected in the operator-dependent field elastic recovery test do not significantly effect the elastic recoveries of the binders, as shown in Section 3.2.

The field elastic recovery test (FERT) therefore has the ability to produce elastic recovery results identical to those obtained from the more expensive and bulky laboratory ductilometer primarily for modified as well as unmodified binders. The simple pull test can therefore be used independently in the field to determine whether a certain binder is within the elastic recovery range specified for that particular binder.

5. CONCLUSIONS

The repeatability of the field elastic recovery test is extremely good, the range of test results being consistently within a 5 percent error limit.

The field elastic recovery test showed a low sensitivity to changes in the testing conditions, which included changes to the elongation rate of 50 mm/min, shortening of the 2 hour conditioning time to 1 hour and slight temperature changes above and below the 10°C testing temperature.

The elastic recoveries obtained from the field elastic recovery test correlated very well with those obtained from the standard laboratory ductilometer for all types of binders. The correlation or relationship consisted of a direct linear relationship with the elastic recovery results from the field elastic recovery test being identical to those from the standard laboratory ductilometer test.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Department of Transport, for funding the research discussed here. This paper is published with the permission of the Director of the Division for Roads and Transport Technology of the CSIR, South Africa.

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