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Improving Precision of Rubber Test Methods: Part 3-Tensile Test

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ABSTRACT

Many interlaboratory test programmes (ITPs) on rubber test methods, have been carried out during the last 10 years. ITPs have been organised within ISO TC 45 and also in several countries such as USA, UK and Sweden. Most of these ITPs have shown that the repeatability and the reproducibility are poor for many rubber test methods. in an attempt to do more than just determine the poor precision, we chose four methods and decided to study them to identify the factors giving poor precision, thereby improving the methods. This third part contains the work done on tensile tests. All of the investigated factors are influencing the results. However, using five test pieces instead of three and having a good calibration status is shown to be very important to improve precision in tensile testing.

1 BACKGROUND

At the beginning of the 1980s it was decided to include within IS0 TC 45, Rubber and Rubber Products, a precision clause in all testing method standards. The precision clauses were established by carrying out interlaboratory test programmes (ITPs) to establish the *repeatability* (within laboratory) and the *reproducibility* (between laboratories) for the test methods.

In 1981 IS0 published a standard for determination of the precision of test methods, IS0 5725-86.[1] In 1984 TC 45 published a technical report, IS0 TR 9272,[2] for guidance on how to establish precision data for rubber test methods. IS0 TC 45 has since then carried out about 25 ITPs.

This work inspired us in Sweden to start an ITP, organised by the Swedish National Testing Institute. During the years 1982-1988, 14 interlaboratory tests were carried out. For two of the methods a retest was done. Up to 25 laboratories participated in these interlaboratory tests.

All these interlaboratory tests within ISO and in Sweden have shown that the spread in the test results is worse than anyone could have expected.

At the same time, the requirements for the products have increased, which means that we need to be able to test the properties of rubber materials with a higher accuracy than before. It must not be the case that what we measure mainly reflects the spread in the testing and does not show the variations in the material tested.

2 THE PURPOSE OF THE PROJECT

The purpose of the project was to achieve a lower spread in test results, within and between laboratories, for the test methods under study. The results from this project will be presented to the Swedish Standards Institution and to IS0 as a basis for improving the test method standards.

This project was started in 1989.

3 PARTICIPATING COMPANIES

The following companies have participated and financed this project:

- Alfa-Lava1 Materials AB
- Forsheda AB
- Horda Compound AB
- Skega AB
- Statens Provningsanstalt
- Sunnex AB
- Trelleborg Industri AB
- Viskafors AB
- Volvo Flygmotor AB
- Volvo PV AB, materiallab
- Värnamo Gummifabrik AB
- Saab-Scania AB, Scaniadivisionen

4 THE ORGANISATION OF THE PROJECT

4.1 General organisation

The following methods have been studied during the project:

- Hardness, normal and micro IRHD, according to IS0 48[3] and Shore according to IS0 7619.[4]
- Tensile test, according to ISO 37.[5]
- Heat ageing, according to IS0 188.[6]
- Temperature retraction test, TR, according to IS0 2921.’

For the TR test only a preliminary study has been made due to lack of money.

Good background was obtainable for all of these methods as all of the tests have been studied one or more times by interlaboratory trials.

The test methods have been studied by investigating the influence of different factors on the spread in test results.

At the beginning of the project a visit was paid to all participating companies to make up an inventory of the type of test instruments that are being used. Some preliminary interlaboratory tests and other measurements were also made.

Before starting the project a literature search was performed (1990), but we found very little published about precision of rubber testing.[8-10] Further papers have been published after 1990.’ [1-14]

4.2 Organisation of the tensile test part

The project started with an ITP, where one person visited all participating laboratories and made observations during the tests. The following details were studied:

- equipment
- test conditions
- test piece preparation
- thickness measurement
- calibration

5 TENSILE TEST RESULTS

The tensile test reproducibility determined in earlier ITP 1987 (Ref. 15) is shown in Table 1.

TABLE 1
Tensile Test Reproducibility

1987 *ITP*	*Mean*	*SD*	*R*[a]	(*R*)[b]
Tensile strength (MPa)	13.9	0·74	2·1	15.1
Elongation at break (%)	504	30.3	85	17·0
Stress at 100% (MPa)	2.5	0·17	0.48	19·4

[a]R, reproducibility in actual units of measurement.
[b](R), reproducibility in % of measured value.

5.1 Preliminary investigatons

5.1.1 Equipment used

The equipment used for the tensile ITP are shown in Table 2.

5.1.2. Test conditions

The test conditions in the different laboratories were as shown in Table 3.

5.1.3. Test piece preparation

The cutting dies and cutting pads were studied (see Table 4).

A further investigation of how these conditions influence the test results has been made. Test pieces prepared in one laboratory were sent to all

TABLE 2
Equipment Used

Company	*Tensile tester*	*Cal*[a]	*Thickness Gauge*	*Cal*[a]
1	Monsanto T 10	Y	Sony Ly-101	?
2	Amsler	Y	Dial Gauge	Y
3	Monsanto T 10	Y	Monsanto	N
4	Zwick 1455	Y	Wallace S4	Y
5	Monsanto T 10	Y	Wallace S4	N
6	Monsanto T 10	Y	Monsanto	N
7	Instron 1162	Y	Sony Ly-101	Y
8	Monsanto T 500	Y	Mitutoyo dial	N
9	Monsanto T 10	Y	Wallace S4	Y
10	Monsanto T 500	Y	Mitutoyo digital	Y
11				
12	Monsanto T 10	Y	Monsanto	N
13	Alwetron TCT 50	?	Mitutoyo dial	N
14	Instron 1101	Y	Mitutoyo digital	Y

[a]Cal. Calibrated between 6 and 12 months before the test.

TABLE 3
Test Conditions“

Company	*Date*	*Temperature (“C)*
1	900316	22.0
2	900427	24·5
3	900627	23·5
4	900320	22.5
5	900829	24.5
6	900315	23.0
7	900715	25.0
8	900827	23.0
9	900404	22-5
10	900420	24.0
11	900830	22.5
12	900829	23·0
13	900904	21.5
14	9104	22.0

‘Specified temperature is 23 ±2°C.

TABLE 4
Test Piece Preparation

Company	*Die condition*	*Pad material*	*Pad condition*
1	Good	PE-sheet 10 mm	Used
2	Good	Fibreboard	Used
3	Fair	PE-sheet	Used coarse surface
4	Fair	PE-sheet	Used coarse surface
5	Excellent	PE-film	New every time
6	Excellent	PE-sheet 5 mm	Used coarse surface
7	Excellent	PE-film	New every time
8	Good	PE-sheet	Used coarse surface
9	Fair	Masonite	Used
10	Poor	PE-sheet	Used coarse surface
11			
12	Good	PE-sheet	Used coarse surface
13	Good	PE-sheet	Used coarse surface
14	Excellent	PVC-cutting mat	Smooth surface

participants for testing and test pieces prepared in the different laboratories were sent to one laboratory for testing.

5.1.4 Thickness measurement

Table 5 shows the size of the pressure foot used and the measurement pressure.

TABLE 5
Thickness Measurement'

Company	*Foot dia. (mm)*	*Pressure (kPa)*
1	6.36	32
2	5·0	30
3	5·0	12 -28
4	3.8	70
5	6·0	27
6	5·0	23
7	6·0	19
8	?	?
9	6.33	20
10	4·0	22
II	—	
12	5·0	29
13	5.98	32
14	4.3	22

"Specified pressure *is* 22 ± 5 k Pa. Specified foot dia. is 2 10 mm.

A further investigation of how the different conditions of thickness testers influence the result have been made by measuring five test specimens each from four rubber compounds first in one laboratory and then in the different laboratories.

5.1.5 Calibration

Table 6 shows the result when attaching the same standard weight of 49.05 N (5 kg) to the different tensile testers.

5.1.6 Test results from the initial ITP

How the reproducibility is calculated is shown in Appendix 1.

All results are the pooled values from four rubber compounds.

Table 7 shows the mean values, standard deviation and reproducibility results from tensile test measurements. Figures 1-3 shows the variation between laboratories graphically. Table 8 shows the mean tensile strengths values for the laboratories and the values after correction according to the results of the calibration. All results are also found in Appendix 2.1.

The results from this ITP are in the same range as found in the 1987 ITP.

When correcting the results according to the result of the calibration, reproducibility improves by 1·8%-units.

TABLE 6
Calibration

Company		*Force (N)*
1		4945
2		
3		49.20
4		48·50
5		49.10
6		50·14
7		48.70
8		48.80
9		49.24
10		49·04
11		
12		49.02
13		50·20
14		49·05
Mean	=	49.20
SD	=	0·52
R	=	1.46
(R)	=	2.97

TABLE 7
Tensile Test

	Mean	*SD*	*R*	*(R)*
Tensile strength (MPa)	15·8	0·65	1.84	11·6
Elongation at break (%)	533	45·6	129	24
Stress at 100% (MPa)	2·2	0.13	0.36	16

5.2 Influence of test piece preparation

In order to investigate the influence from test piece preparation, two tests were done.

5.2.1 Thickness measurement

An investigation of how the different conditions of thickness testers influence the result has been made by measuring five test specimens each from four rubber compounds first in one laboratory and then in the different laboratories.

The results show that the mean difference is 0.015 mm, corresponding to a reproducibility of $R = 0{\cdot}025$ mm. This is the result from measuring 220

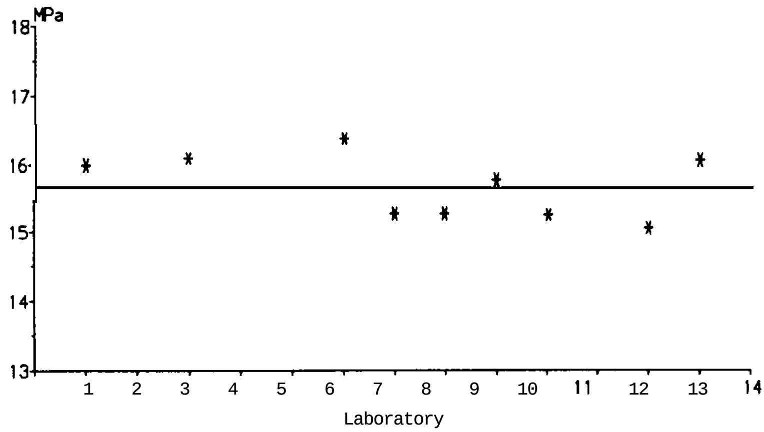

Fig. 1. Tensile strength, variation between laboratories (mean of four materials).

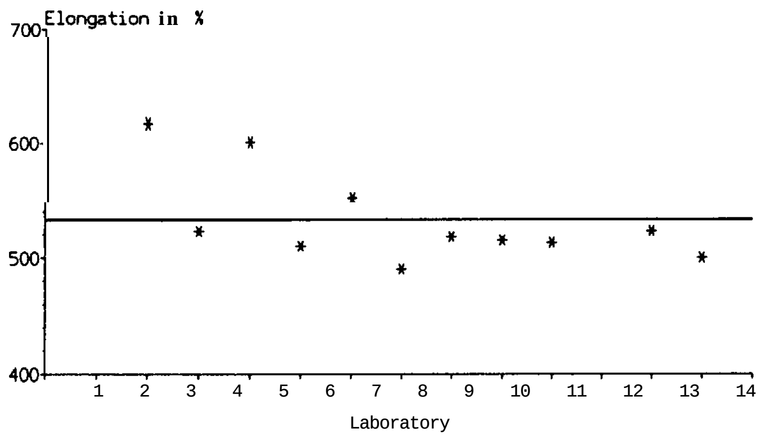

Fig. 2. Elongation at break, variation between laboratories (mean of four materials).

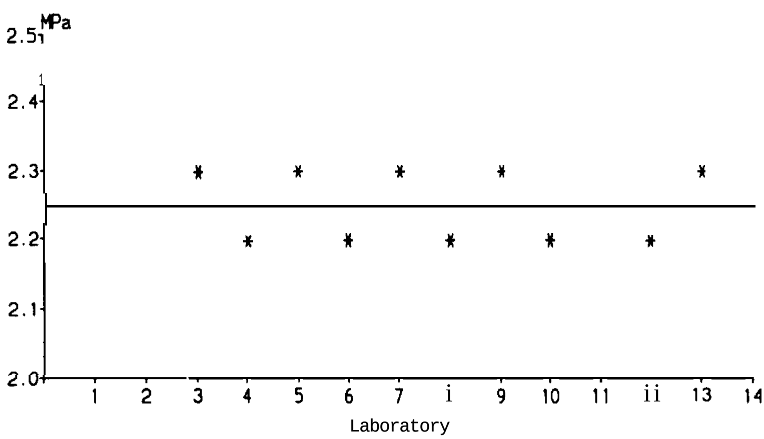

Fig. 3. Stress at 100%, variation between laboratories (mean of four materials).

TABLE 8
Mean (n =4) Tensile Strength after Correction

Company		*Tensile strength (MPa)*	
		As measured	*Corrected*
1		16·0	15·9
2		(16.4)	
3		16·1	16·1
4		15·7	15·9
5		15·7	15.7
6		16.4	16·0
7		15·3	15·4
8		15.3	15.4
9		15·8	15.7
10		15-3	15.3
11			
12		15·1	15.1
13		16.1	15·7
14			
Mean	=	15.7	15.7
SD	=	0.42	0·32
R	=	1·19	0.91
(R)	=	7·6	5·8

test pieces first in one laboratory and then in 11 other laboratories (see Appendix 2.2).

Taking the mean tensile strength of the four rubber compounds, 17 MPa, and calculating the effect of a thickness difference of 0·025 mm, shows that this will give a difference of 1·2% in the result of tensile strength.

5.2.2 Cutting of test pieces

An investigation of how the cutting conditions influence the test results have been made. Test pieces prepared in one laboratory were sent to all participants for testing and test pieces prepared in the different laboratories were sent to one laboratory for testing. The results are shown in Tables 9 and 10, Figs 4 and 5, and Appendix 2.3.

The influence from the cutting of test pieces shows mainly in the tensile strength and test pieces cut in the same laboratory show 1·3%-units better reproducibility, than test pieces cut in the different laboratories. The reproducibility of the elongation at break, seems however mainly to reflect the accuracy of the extensometer used.

TABLE 9
Test pieces prepared in one laboratory and tested in each laboratory

	Mean	*SD*	*R*	*(R)*
Tensile strength (MPA)	165	0·51	1·44	8.7
Elongation at break, (%)	462	29	83	18·1
Stress at 100% (MPa)	2·4	0.13	0·37	15·0

TABLE 10
Test pieces prepared in each laboratory and tested in one laboratory

	Mean	*SD*	*R*	*(R)*
Tensile strength (MPa)	17.0	0.60	1.70	10·0
Elongation at break (%)	435	13	37	8·6
Stress at 100% (MPa)	2·8	0.19	0·53	19·0

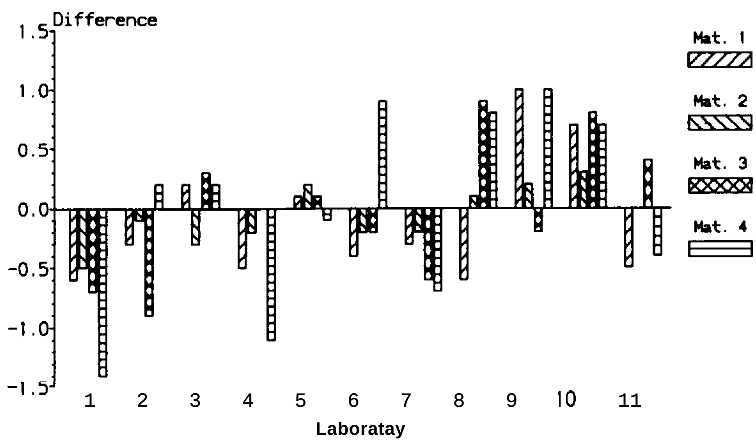

Fig. 4. Test pieces prepared in one laboratory and tested in each laboratory.

5.3 Influence of number of test pieces

The test pieces prepared in one laboratory and tested in each of the 11 laboratories were used for this investigation. There were a total of 44 test series with five test pieces in each.

To see the difference between three and five test pieces the results were first calculated only on the first three test pieces. After that the results were calculated on all five test pieces. The results are shown in Table 11 and Appendix 2.4.

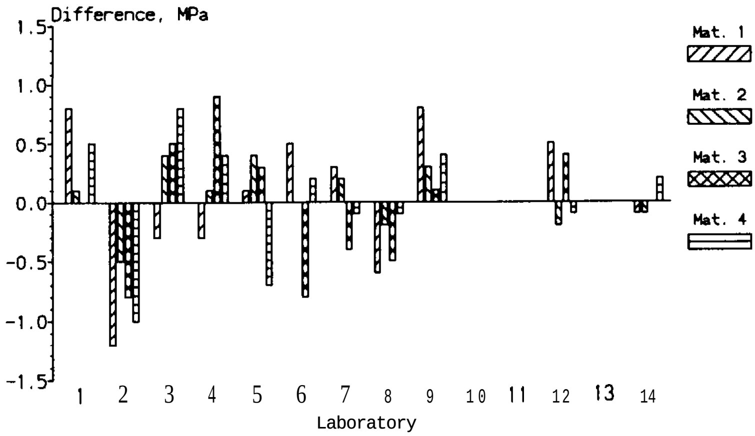

Fig. 5. Test pieces prepared in each laboratory and tested in one laboratory.

TABLE 11
Comparison between Three and Five Test Pieces

	Mean	*SD*	*R*	(*R*)
Three test pieces				
Tensile strength (MPa)	16.6	0·62	1.75	10.6
Elongation at break (%)	459	31	88	19.1
Stress at 100% (MPa)	2·4	0·13	0.37	15.3
Five test pieces				
Tensile strength (MPa)	16.5	0.51	144	8.7
Elongation at break (%)	459	29	82	17.9
Stress at 100% (MPa)	2.4	0.13	0.37	15.3

Using five test pieces compared to three, when doing tensile tests, shows an improvement in the reproducibility of 1·9%-units in the tensile strength. The elongation at break shows also an improvement.

6 FACTORS INFLUENCING THE RESULT

The different factors being investigated contributes in about the same degree to the reproducibility: no single factor can be 'blamed' more than the other.

Having a good control of the above factors it may be possible to reduce the reproducibility (*R*) for tensile strength by about 50%.

TABLE 12
Summary of Influencing Factors

	Contribution to (R) Tensile strength (%-units)
Calibration	1·8
Thickness measurement	1.2
Cutting of test pieces	1.3
Using five instead of three test pieces	1·9

REFERENCES

1. IS0 5725-86. Precision of test methods-Determination of repeatability and reproducibility for a standard test method by inter-laboratory tests.
2. IS0 TR 9272-86. Rubber and rubber products-Determination of precision for test method standards.
3. IS0 48-79. Vulcanized rubbers-Determination of hardness.
4. IS0 7619-86. Rubber-Determination of indentation hardness by means of pocket hardness meters.
5. IS0 37-77. Rubber, vulcanized—Determination of tensile stress-strain properties.
6. IS0 188-82. Rubber, vulcanized-Accelerated ageing or heat resistance tests.
7. IS0 2921-82. Rubber vulcanized-Determination of low temperature characteristics-Temperature-retraction procedure (TR-Test).
8. Veith, A. G., Precision in polymer testing, an important world-wide issue. Polym. Testing, **7(4)** (1987) 239-67.
9. Kern, W. F., Statistical evaluation through application of repeatability and reproducibility. *Kautchuk u. Gummi Kunstoffe*, **35**(4) *(1982) 279-97.*
10. Brown, R., Faith, hope and testing. European *Rubber J.*, **Jan/Feb (1989) 25.**
11. Levin, N. M., Demands on testing and quality technique in the 1990s. Polym. *Testing, 9* (1990) 315-27.
12. Brown, R. P. & Soekarnein, A., An investigation of the reproducibility of rubber hardness tests. Polym. *Testing,* **10** (1991) 117-37.
13. Veith, A. G., A new approach to evaluating inter-laboratory testing precision. *Polym. Testing, 12* (1993) 113-84.
14. Bille, H. & Fendel H., How to do hot air ageing tests properly. Paper presented at ACS Rubber Division Meeting, May 1993, Denver, CO, USA.
15. Spetz, G., Jämförande gummiprovning-gummimaterial. Del 6 Bestlmning av draghallfasthet enligt SIS 16 2202 (IS0 37). SP Rapport 1988:25 ISBN 91-7848-115-5, ISSN 0284-5172.

APPENDIX 1

How to calculate the repeatability and reproducibility

n = number of measured values
x_i = measurement 1, 2, 3 . . . n
$\bar{x}$ = mean value $\bar{x} = \frac{\Sigma x_i}{n}$

$\bar{s}$ = mean value (pol) $\bar{s} = \sqrt{\frac{\Sigma (s_i)^2}{n}}$

The pol mean value is used when calculating mean values of standard deviation and coefficients of variation.

SD = standard deviation SD = $\sqrt{\frac{\Sigma (x_i - \bar{x})^2}{n - 1}}$

SD_L = standard deviation between laboratories
SD, = standard deviation within laboratories

v = coefficient of variation $v = \frac{SD}{\bar{x}} 100$

v_L = coefficient of variation between laboratories
r = repeatability r = 2.83 SD,
R = reproducibility $R = 2.83 \sqrt{SD_L^2 + SD,'}$

If the repeatability is not calculated SD, = 0

Definition: An established value, below which the absolute difference between two ‘between-laboratory’ test results may be expected to lie, with a specified probability. The probability is normally 95% if nothing else is specified.

(R) = Reproducibility expressed as a percentage of the mean value of the measured values.

Extreme values are checked with Dixon’s Outlier Test.

APPENDIX 2.1

Tensile Test (Tensile Strength in MPa)

Laboratory	*Material*				*Mean*	*Corrected with regard to calibration*
	1	2	3	4		
1	24.3	16.5	12.9	10.3	16.0	15.9
2	25.0	17.9	13.2	9.3	16·4	
3	24.6	16.5	12.6	10·5	16·1	16.1
4	24.0	161	12·9	9·8	15.7	15.9
5	23.9	16·5	12.8	9·5	15.7	15.7
6	24.1	17.1	14.2	10.3	16.4	160
7	23.7	16·0	11.9	9·7	15·3	15.4
8	22.8	16.2	13.1	9.1	15.3	15·4
9	23·5	16.9	12.8	9.8	15.8	15.7
10	24.3	15·0	13.2	8.8	15·3	15.3
11						
12	22.4	15.5	13.3	9.2	15.1	15.1
13	24.3	16.7	13.7	9.7	16.1	15.7
Mean	23.9	16.4	13.1	9·7	15·8	15.7
SD	0.73	0.75	0.57	0.52	0·44	0·32
SD (pool)	065	*R*	1.84	(*R*)	11.6	

Tensile Test (Elongation at Break in %)

Laboratory	*Material*				*Mean*
	1	2	3	4	
1					
2	640	630	560	640	618
3	500	560	460	570	523
4	600	620	590	600	603
5	520	530	450	540	510
6	530	560	530	590	553
7	520	490	410	540	490
8	530	520	480	540	518
9	540	520	440	560	515
10	550	500	470	530	513
11					
12	520	500	510	560	523
13	500	490	470	540	500
Mean	541	538	488	565	533
SD	42·8	49.4	54·0	33.6	
SD (pool)	45.6	*R*	129	(*R*)	24

Tensile Test (Stress at 100% Elongation in MPa)

Laboratory	*Material*				*Mean*
	I	2	3	4	
1					
2					
3	2.6	1.9	2.2	2.3	2.3
4	2·5	1·8	2.2	2.1	2.2
5	2·6	2·0	2.4	2.3	2.3
6	2·4	2·0	2·1	2·3	2.2
7	2.5	2.1	2.4	2·3	2·3
8	2·3	2.1	2.1	2·1	2.2
9	2.4	2.2	2.2	2·2	2·3
10	2.3	2·0	2.2	2·1	2·2
11					
12	2.2	2.1	2·1	2·2	2.2
13	2.6	2.3	2·0	2·2	2·3
Mean	2·4	2.1	2.2	2·2	2.2
SD	0·14	0·14	0.13	0·09	
SD (pool)	0.13	*R*	0.36	(*R*)	16

APPENDIX 2.2

Thickness Measurement:
Measurement of five Test Pieces each of four Compounds

Lab.	*Measured at each laboratory*					*Measured in one laboratory*						
	1	2	3	4	***Mv1***	*1*	2	3	4	***Mv2***	***Mv2-Mv1***	
1	2.00	1.84	2.03	2.07	1.99	2.02	1.86	2.04	2.10	2.01	0.02	
2	1.90	1.86	2.05	2.02	1.96	1.97	1.93	2.12	2.10	2.03	(0.07)	Extreme value
3	1.98	1.96	2.04	2.09	2.02	1.99	1.98	2.08	2.12	2.04	0.02	
4	2.03	1.94	2.15	2.06	2.05	2.01	1.94	2.16	2.08	2.05	0.00	
5	2.07	1.94	2.03	2.13	2.04	2.09	1.96	2.06	2.14	2.06	002	
6	2.09	1.92	2.06	2.03	2.03	2.09	1.94	2.07	2.04	2.04	0.01	
7	1.90	1.98	2.02	2.10	2.00	1.90	1.98	2.04	2.11	2.01	0-01	
8	2.03	1.95	2.09	2.00	2.02	2.04	1.96	2.12	2.02	2.04	0.02	
9	2.0	1.9	2.1	2.1	2.03	1.99	1.95	2.13	2.11	2.05	0.02	
10												
11												
12	2.06	1.95	2.10	2.02	2.03	2.06	1.96	2.11	2.03	2.04	0.01	
13												
14	1.93	1.92	1.99	1.96	1.95	1.94	1.93	2.02	1.97	1.97	0.02	
								Mean diff.			0.015	
								SD			0.009	
								R			0.025	

APPENDIX 2.3

Tensile Test-Median value of five test pieces

Material 1. Test pieces prepared in one laboratory and tested in each laboratory				*Material 1. Test pieces prepared in each laboratory and tested in one laboratory*			
Laboratory	*Tensile strength* (*MPa*)	*F 100%* (*MPa*)	*Elongation at break* (%)	*Laboratory*	Tensile strength (*MPa*)	*F 100%* (*MPa*)	*Elongation at break* (%)
1	16.3	2·6	480	1	16.2	2.9	440
2	14.3		450	2	16.3	2.9	460
3	15.2	2.5	480	3	16.7	2.9	480
4	15.2	2·4	530	4	15.6	2.9	460
5	15.6	2·5	490	5	15.7	2.9	440
6	16.0	2·5	500	6	15.8	2.8	450
7	15.8	2.6	480	7	15.6	2.6	460
8	14.9	2·4	470	8	15.8	2.8	480
9	16.3	2.6	490	9	16·8	3.5	440
10				10			
11				11			
12	16.0	2.4	510	12	17.1	3.1	470
13				13			
14	15.4	2.7	470	14	15.5	2.9	450
Mean	15.5	2.5	486	Mean	16.1	2.9	457
SD	0·62	0·10	22	SD	0.56	0.22	15

Material 2. Test pieces prepared in one laboratory and tested in each laboratory				*Material 2. Test pieces prepared in each laboratory and tested in one laboratory*			
Laboratory	*Tensile strength (MPa)*	*F 100% (MPa)*	*Elongation at break (%)*	*Laboratory*	*Tensile strength (MPa)*	*F 100% (MPa)*	*Elongation at break (%)*
1	9.7	2·3	460	1	10.0	2.5	440
2	9.1		440	2	10·1	2.5	440
3	10·0	2·3	470	3	9.9	2.6	440
4	9·7	2.2	500	4	9.6	2.5	440
5	10.0	2.3	470	5	9.6	2.5	420
6	9.6	2.2	460	6	9·6	2.4	440
7	9.8	2.3	440	7	9.8	2.4	440
8	9.4	2.2	450	8	9.7	2·4	450
9	9.9	2.3	460	9	10·1	2·5	430
10				10			
11				11			
12	9·4	2.2	450	12	10·0	2.4	440
13				13			
14	9·5	1.9	440	14	9.3	2.4	440
Mean	9.6	2.2	458	Mean	9.8	2·5	438
SD	0·28	0.12	18	SD	0·25	007	8

Material 3. Test pieces prepared in one laboratory and tested in each laboratory				Material 3. Test pieces prepared in each laboratory and tested in one laboratory			
Laboratory	Tensile strength (*MPa*)	F 100% (*MPa*)	Elongation at break (%)	Laboratory	Tensile strength (*MPa*)	F 100% (*MPa*)	Elongation at break (%)
1	16.6	2.9	340	1	17.5	3·0	340
2	15.8		340	2	17.7	2.9	330
3	17.1	2·7	360	3	18·3	3·5	350
4	17.5	2.6	450	4	(15.3)	3.1	320
5	16.9	3·0	360	5	17.2	3.5	320
6	15.8	2·7	350	6	16.8	3.1	330
7	16-2	2.9	320	7	17.8	3.2	340
8	16.1	2.5	360	8	16.5	2.9	330
9	16.7	2.8	350	9	18.2	3·0	350
10				10			
11				11			
12	17·0	2.6	360	12	17.2	3·1	330
13				13			
14	16.6	2·7	350	14	167	2·9	340
Mean	16.6	2.7	358	Mean	17.4	3.1	335
SD	0.55	0.16	33	SD	0.62	O-22	10

Material 4. Test pieces prepared in one laboratory and tested in each laboratory

Laboratory	*Tensile strength* (*MPa*)	*F 100%* (*MPa*)	*Elongation at break* (%)
1	24.8	2.4	510
2	23.3		520
3	25·1	2·2	550
4	24·7	2.3	630
5	23.6	2.3	490
6	245	2·3	520
7	24.2	2·4	480
8	24.2	2·1	510
9	24·7	2.2	520
10			
11			
12	24·2	2.2	540
13			
14	24.5	2·0	540
Mean	24.3	2·2	528
SD	0.53	0·13	40
SD (pool)	0·51	0·13	29
R	1·44	0·37	83
(*R*)	8.7	15·0	18.1

Material 4. *Test pieces prepared* in *each laboratory and tested in one laboratory*

	Laboratory	*Tensile strength* (*MPa*)	*F 100%* (*MPa*)	*Elongation at break* (%)
	1	24·7	2.5	490
	2	25.0	2.4	490
	3	25.6	2·6	520
	4	23.7	2.8	460
	5	25·7	2.5	510
	6	24·1	2·5	490
	7	24.4	2.5	490
	8	25.0	2.5	520
	9	25.5	3-o	490
	10			
	11			
	12	25.8	2.8	490
	13			
	14	23.4	2.4	480
	Mean	24.8	2.6	494
	SD	083	0·19	17
all four	SD (pool)	0·60	0·19	13
materials		1·70	0.53	37
		10.0	19.0	8.6

APPENDIX 2.4

Comparison between using three or five test pieces—44 test series, using three and five test pieces for calculation of result

Material	Three test pieces			Fiae test pieces		
	Tensile strength (MPa)	*F 100% (MPa)*	*Elongation at break (%)*	*Tensile strength (MPa)*	*F 100% (MPa)*	*Elongation at break (%)*
1	15.7	2.5	492	15.5	2.5	486
2	9.6	2.2	457	9.6	2.2	458
3	16.8	2·7	362	16.6	2.7	358
4	24.1	2·2	526	24.3	2.2	528
Mean	16.6	2.4	459	16.5	2.4	458
SD (pool)	0·62	0·13	31	0.51	0·13	29
R	1.75	037	88	1·44	0.37	82
(*R*)	10·6	15.3	19·1	8·7	15.3	17.9

APPENDIX 3

Formulation of Rubber compounds used for testing

	Parts per hundred
1. NR	
NR	100
Carbon Black N330	50
Aromatic oil	6
ZnO	5
Stearic acid	1·5
Micro vax	2
Antioxidant, TMQ	1·0
Accelerators	2·1
Sulphur	1.6
2. *SBR*	
SBR	100
Carbon Black N330	50
Aromatic oil	6
ZnO	5
Stearic Acid	1·5
Micro vax	2
Antioxidant, TMQ	1·0
Accelerators	2·1
Sulphur	1·6
3. *NBR*	
NBR 33% ACN	100
Carbon Black N550	55
Plasticiser DOA	10
Activators	5
Protection	5
Accelerators	4·5
Sulphur	0·5
4. EPDM	
EPDM	loo
Carbon Black N550	100
Whiting	75
Paraffin oil	100
Activators	6
Accelerators	5·75
Sulphur	1.25