A Correlation between Truck Tyre Road Wear Performance and a System of Laboratory Abrasion Tests.

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Key words: **Abrasion, tyre wear, correlation, energy dissipation, slip, slip speed**

Abstract
During a European Craft project to help to improve the quality of re-treaded tyres, road wear tests were conducted and the results were compared with standard laboratory abrasion tests using the DIN abrader and the Standard Akron abrader. In addition a laboratory test method was developed with a prototype abrasion tester using the slipping wheel principle. Whilst no correlation could be obtained with the two standard abrasion tests the new method gave high correlations with all the road results.
The paper discusses the method employed briefly, since it has been discussed in the literature before and concentrates on the way to ensure high correlations with road test results. It is based on several well chosen testing conditions varying essentially the severity of the test as indicated by slip and speed conditions The correlations to road tests are discussed in detail. These show that high correlations are only obtained over a very narrow range of testing severities and these vary with the road use of the tyre. Conversely, tyre wear performance can only be predicted if the laboratory tests are covering a sufficiently large field of severities. The paper discusses, how this can be achieved with a reasonable economic effort.

1. Introduction

There is a considerable scepticism whether it is possible to predict tyre wear in service from laboratory abrasion measurements. The reason is that tyre wear is influenced by a large number of ill-controlled factors often to such an extent that reversals in ranking are observed. This alone limits laboratory test procedures based on a single testing condition to a very narrow range of road wear experience, quite apart from the fact that it would be difficult to find such a testing condition.
During the BRITE EURAM CRAFT project BE-S2-2076 for the improvement of the quality of re-tread tyres, the wear performance of truck tyres was subject to a research program with

the objective to develop a laboratory method which allows a reliable quality control of existing compounds and a trustworthy tool to evaluate the wear performance of newly developed compounds in the laboratory without costly and lengthy road trials. H. Moneypenny reported already on the results obtained with the standard Din abrader, using different types of abrasive paper and on results with the Akron Abrader using different slip angles and applying dust to the track. Neither method produced results which correlated with the results from road trials which were conducted during the course of this project (1). K.A. Grosch had developed a method to measure abrasion which is based on the slipping wheel principle used also in the Akron Abrader, but which employs a wide range of slip angle-, load-, and speed settings, as well as varying the type of abrasive disk. (2, 3, 4,5). This method was further developed during the Craft program using the same compounds for which also road data were obtained, allowing a direct check to what extent laboratory results could be correlated with laboratory measurements.

2. Experimental

2.1 Road Tests

All tyres used in the trials were worn out first life tyres of the same manufacture which were re-treaded with the experimental compounds. Tyres which were tested in the UK were 11 R 22.5, those tested in continental countries were 12 R 22.5 and 315/80 R 22.5. Some tests were run with tyres on which the full tread consisted of the experimental compound. In this case the tyres were mounted on the drive axles of tippers and tractor units. In each case two experimental tyres were placed on one side of the axle and two tyres with the control compound on the other side. About halfway through the test the positions were reversed.
A considerable number of tyres run in the UK under the direct control of TARCC were tri-section tyres with two sections made up of different experimental compounds, the third always being the same control compound.
Two groups of compound were used. The first group consisted of three compounds supplied by three different retreading companies representing typical truck tyre polymer combinations NR-SBR, NR-BR and SBR-BR. These were run as whole tyres as well as tri-section tyres. The second group, supplied by Cabot consisted of seven compounds having the same polymer formulation but different types of carbon black filler. This group was run only in tri-section tyres. Tread depth measurements were carried out at regular intervals.

2.2 Laboratory abrasion measurements.

Figure 1 shows a diagrammatic view of the apparatus employed. The rubber sample wheels

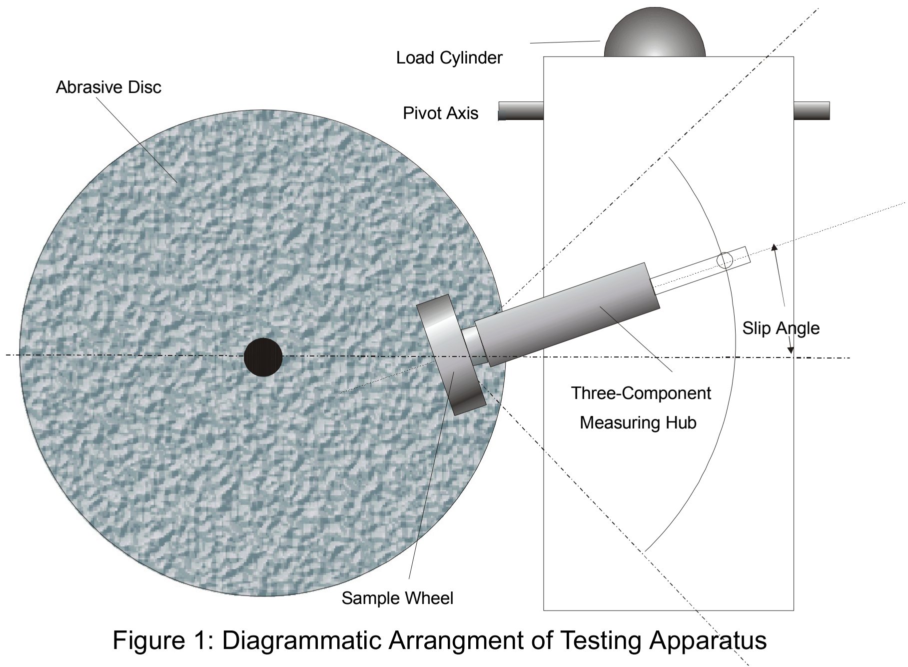


Figure 1: Diagrammatic Arrangment of Testing Apparatus

runs under a set slip angle and load on the flat side of an abrasive disk at a given speed. Slip angle, load and speed can be varied over a wide range. The abrasive disks used were made of high grade Alumina, with different grain size. Powder is fed between track and sample to avoid smearing of the sample due to thermal-oxidative degradation of the rubber during the abrasion process (2, 3). During the experiment, the side force generated on the test wheel by the slip angle is monitored.

In order to be able to cover a wide range of experimental conditions which are necessary to reflect the complex abrasion behaviour of compounds an experimental design is required. The one employed has been worked out on two basic facts which have emerged from extensive abrasion research:

a. Abrasion is a function of the energy dissipation in the contact area of the slipping sample wheel.

This can be expressed mathematically by

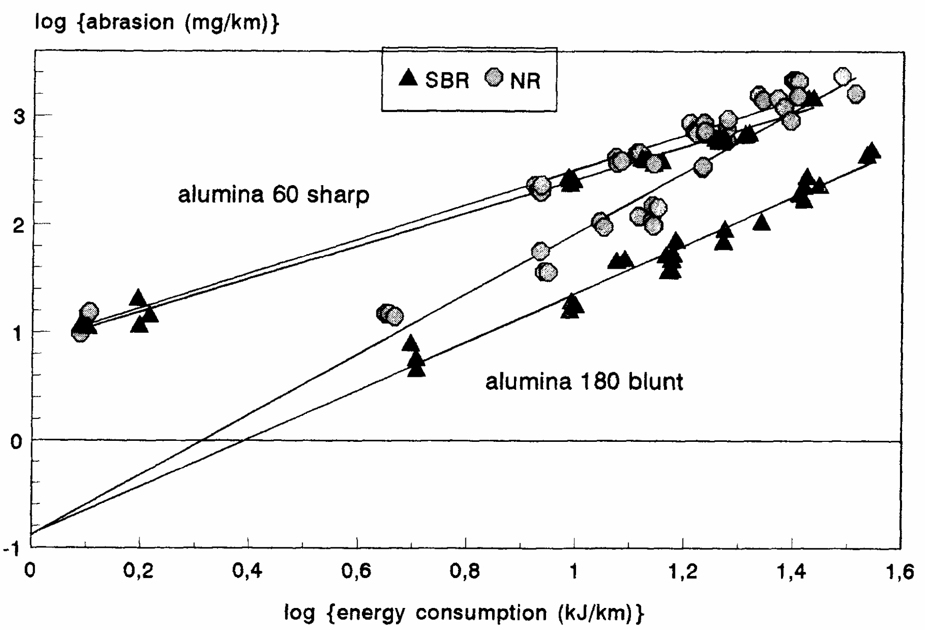
$$A = A_{vo} \cdot \left\{ \frac{U}{U_{vo}} \right\}^{n} \qquad (1)$$

The energy dissipation in a slipping wheel is given by (6)

$$U = F \cdot \sin\alpha \text{ (kJ/km)} \qquad (2)$$

Since the side force F at a given slip angle and load is measured directly in the present set up the energy dissipation is known. Plotting the log (abrasion loss per km) as function of the log (energy dissipation), obtained by different settings of slip angle and load gives always straight line graphs as shown in figure 2. The slopes of these lines depends on the rubber compound

Figure 2: Log Abrasion Loss vs log Energy Dissipation
on Two Surfaces of Different Sharpness: NR vs SBR Tread
Speed: 19 km/h



and the sharpness of the abrasive track so much so that cross-over are observed i.e. the ranking of compounds can reverse.

b. The abrasion at a given energy dissipation (set slip angle and load) depends on the speed of the abrasive disk in the contact area as shown in figure 3.

Again straight line graphs are obtained when plotting log (abrasion) against log (speed). This behaviour can be described by

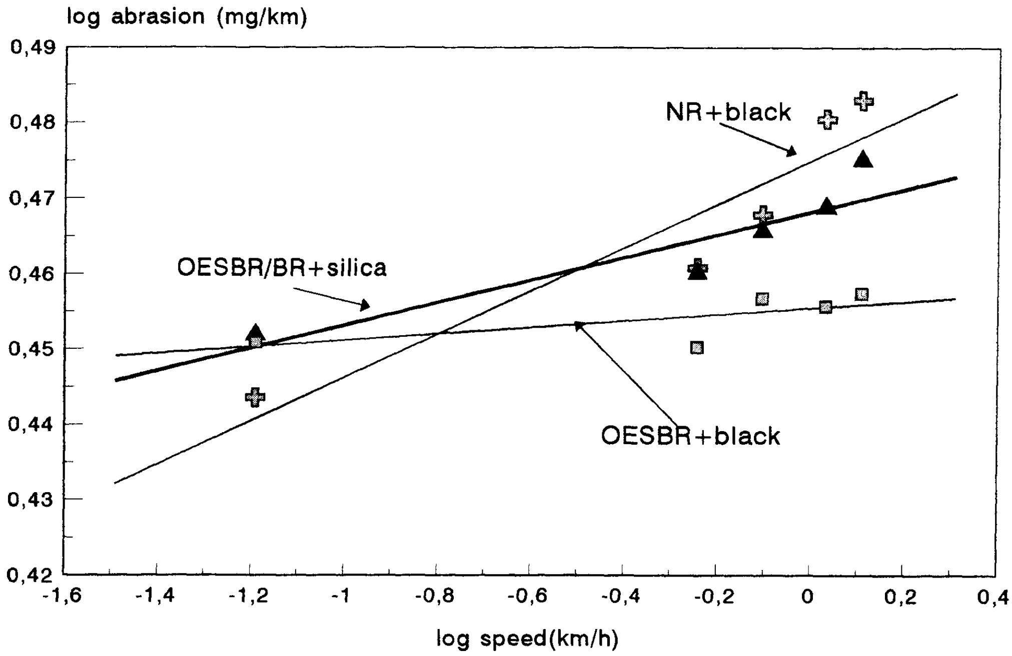
$$A = A_{Uo} \cdot \left\{ \frac{v}{v_{uo}} \right\}^{m} \qquad (3)$$

where v= forward speed in the contact area

These lines, too, cross, indicating that compounds can reverse their ranking with speed at a constant energy dissipation as shown in figure 3 for three tread compounds based on different rubbers and fillers.

These equations can be combined on a linear basis if logarithmic quantities are used

Figure 3: Log Abrasion vs log (forward speed) of Three Tread Compounds; Alumina 60; Slip angle 15°; Load: 57 N



$$z = a + b_1 \cdot x + b_2 \cdot y + b_3 \cdot xy, \qquad (4)$$

where x = log (energy), y = log(speed) and z = log(abrasion)

The product term of xy allows for an interaction between energy and speed on abrasion, which can come about because both change the surface temperature of the sample in the contact area when the energy dissipation or the speed are changed. This has obviously a strong effect on abrasion.

In order to evaluate the four coefficients of equation 4 at least four different testing conditions are required, two different energy settings i.e. slip angle and/or load and two speed settings, both on a logarithmic scale. Because of the statistical nature of abrasion, repeat measurements

Figure 4 Abrasion Test Conditions and Inter- and Extrapolation of Results to Cover a Wide Range of Possible Testing Conditions

energy (kJ/km)	**speed (km/h)** 1	1.6	2.5	4.0	6.3	10.0	15.8	25.1	39.8
1.0									
1.6									
2.5									
4.0									
6.3									
10.0									
15.8									
25.1									
39.8									

are necessary and more testing conditions in the testing scheme than four are desirable. A possible scheme and one which has been used extensively is shown in figure 4. The log energy- and log speed range are each divided into 8 boxes corresponding to a testing condition within the box range of 0.2 log energy and 0.2 log speed between a total range of 1.6 for each variable this corresponds to a factor of about 40 for speed and energy and because of the non linear dependence of abrasion on these variables a volume loss range of about 1 to 1000. The extreme points of the range cannot be used sensibly for actual experimental conditions. The setting for highest energy and speed produces an abrasion volume loss which is hardly ever produced in tyre wear although it can be realised. The lowest setting produces abrasion loss rates which are so small that it takes too long a time to obtain a reasonable weight loss of the sample. Therefore, the choice as indicated in figure 4. If more testing conditions are employed they are best placed in-between the four extreme settings (red boxes) as indicated by the yellow boxes for the next most important settings and the blue boxes for a complete three level design. Using the coefficients obtained thus by a multiple regression analysis, all boxes are filled with calculated abrasion losses as best

Table I: Ratings of Four Compounds as Function of log Energy and log Speed together with Road Test Ratings

road test rating	log U	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
		compound 1			log vf					
	0	51.8	57.5	63.8	70.7	78.5	87.1	96.7	**107.3**	**119.0**
	0.2	58.9	63.2	67.9	73.0	78.4	84.3	90.6	97.3	**104.6**
	0.4	66.9	69.6	72.4	75.4	78.4	81.6	84.9	88.3	91.9
87	0.6	76.0	76.6	77.2	77.8	78.3	78.9	79.5	80.1	80.7
	0.8	86.4	84.3	82.3	80.3	78.3	76.4	74.5	72.7	70.9
	1	98.3	92.8	87.7	82.8	78.2	73.9	69.8	66.0	62.3
	1.2	**111.7**	**102.2**	93.5	85.5	78.2	71.5	65.4	59.9	54.8
	1.4	**127.0**	**112.5**	99.6	88.2	78.1	69.2	61.3	54.3	48.1
	1.6	**144.3**	**123.8**	**106.2**	91.1	78.1	67.0	57.5	49.3	42.3
100		**compound 2 = control=100**								
		compound 3								
	log U	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
	0	91.9	**105.0**	**120.1**	**137.3**	**157.0**	**179.5**	**205.2**	**234.7**	**268.3**
	0.2	97.9	**106.7**	**116.3**	**126.7**	**138.1**	**150.4**	**163.9**	**178.6**	**194.6**
	0.4	**104.4**	**108.4**	**112.6**	**116.9**	**121.4**	**126.1**	**130.9**	**135.9**	**141.1**
107	0.6	**111.3**	**110.2**	**109.0**	**107.9**	**106.8**	**105.6**	**104.5**	**103.5**	**102.4**
	0.8	**118.7**	**111.9**	**105.6**	99.5	93.9	88.5	83.5	78.7	74.2
	1	**126.6**	**113.7**	**102.2**	91.9	82.6	74.2	66.7	59.9	53.9
	1.2	**134.9**	**115.6**	99.0	84.8	72.6	62.2	53.2	45.6	39.1
	1.4	**143.9**	**117.4**	95.8	78.2	63.8	52.1	42.5	34.7	28.3
	1.6	**153.4**	**119.3**	92.8	72.2	56.1	43.7	34.0	26.4	20.5
		compound 4								
	0	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
	0	68.1	88.0	**113.7**	**147.0**	**190.0**	**245.5**	**317.3**	**410.1**	**530.0**
	0.2	75.1	92.5	**114.0**	**140.4**	**172.8**	**212.9**	**262.2**	**322.8**	**397.6**
	0.4	82.9	97.3	**114.2**	**134.0**	**157.3**	**184.6**	**216.6**	**254.2**	**298.3**
170	0.6	91.5	**102.3**	**114.4**	**127.9**	**143.1**	**160.0**	**178.9**	**200.1**	**223.8**
	0.8	**101.0**	**107.6**	**114.6**	**122.2**	**130.2**	**138.7**	**147.8**	**157.5**	**167.9**
	1	**111.4**	**113.1**	**114.9**	**116.6**	**118.4**	**120.3**	**122.1**	**124.0**	**125.9**
	1.2	**122.9**	**118.9**	**115.1**	**111.4**	**107.8**	**104.3**	**100.9**	97.6	94.5
	1.4	**135.6**	**125.1**	**115.3**	**106.3**	98.0	90.4	83.4	76.9	70.9
	1.6	**149.7**	**131.5**	**115.5**	**101.5**	89.2	78.4	68.9	60.5	53.2

estimates obtained from the limited number of the selected testing conditions. The more repeat measurements and the more testing conditions are used the better the estimates. Once abrasion values have been calculated, they can also be referred to a reference compound for each box, thus obtaining the compound wear performance over a wide range of testing conditions in relation to a known reference compound. An example is shown in table I for four passenger tyre compounds for which also road test results were available. It is seen that compound 2 is poorer than the reference over almost the whole range of testing conditions whilst compound 3 is only better over a limited range and compound 4 is better over most testing conditions.

If a set of road test results are available, as is the case here a correlation analysis can be carried out between the road test ratings and the laboratory ratings for each of the testing conditions corresponding to one box of the each of the compound tables in table I. This is shown in table II. Three quantities are obtained:

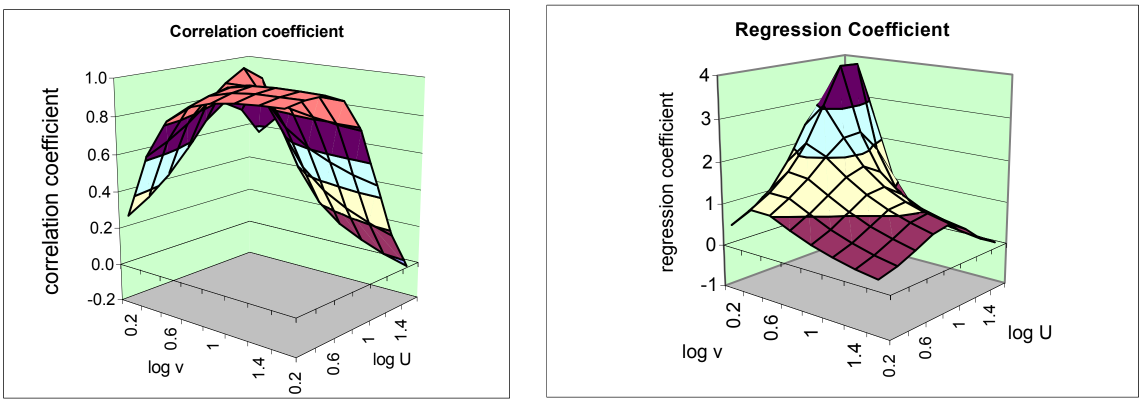
Table II: Correlation between laboratory ratings of compounds of table I
on alumina 180 and road test ratings

					log v				
	log U	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
correlation coefficent	0.2	0.283	0.623	0.824	0.911	0.949	0.965	0.973	0.978
	0.4	0.354	0.678	0.866	0.947	0.978	0.990	0.993	0.993
	0.6	0.444	0.746	0.906	0.970	0.993	**0.999**	0.998	0.996
	0.8	0.564	0.829	0.935	0.961	0.962	0.959	0.954	0.951
	1	0.698	0.925	0.923	0.877	0.839	0.812	0.793	0.782
	1.2	0.778	0.988	0.830	0.693	0.607	0.548	0.505	0.473
	1.4	0.717	0.916	0.635	0.447	0.338	0.267	0.213	0.169
	1.6	0.563	0.677	0.395	0.215	0.114	0.048	0.000	-0.037
		0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
regression coefficient	0.2	0.55	1.03	1.02	0.81	0.60	0.45	0.34	0.26
	0.4	0.78	1.30	1.28	1.04	0.80	0.62	0.48	0.38
	0.6	1.13	1.68	1.62	1.33	1.06	0.85	0.69	0.56
	0.8	1.72	2.25	2.02	1.63	1.32	**1.08**	0.91	0.78
	1	2.52	3.07	2.38	1.77	1.38	1.14	0.97	0.86
	1.2	3.04	3.94	2.41	1.51	1.08	0.83	0.68	0.59
	1.4	2.51	3.92	1.88	0.96	0.58	0.39	0.28	0.20
	1.6	1.55	2.60	1.08	0.42	0.18	0.07	0.00	-0.04
					log vf				
	log U	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
ordinate intercept	0.2	67	13	4	17	33	46	57	64
	0.4	43	-13	-20	-3	17	33	46	56
	0.6	6	-52	-51	-26	-2	18	33	45
	0.8	-57	-110	-87	-48	**-17**	**6**	23	35
	1	-148	-194	-116	-52	-11	14	31	42
	1.2	-216	-286	-114	-20	25	49	64	74
	1.4	-170	-287	-59	35	71	88	97	103
	1.6	-68	-153	17	82	103	112	116	118

The correlation coefficient, the regression coefficient which is the slope of the straight line graph between road and laboratory ratings and the intercept of the ordinate. Clearly if the correlation coefficient is 1 all points lie on a straight line. The regression coefficient, however is also important. If it is nearly 1 the laboratory- and road rating are both of the same magnitude, if it is smaller than 1 and the laboratory rating is shown on the x-axis, the spread of the compounds between lowest and highest rating is larger in the laboratory than on the road and the reverse is true if the regression coefficient is larger than 1. The table indicates at which single testing condition a high correlation would have been achieved.. This condition could be used in future for quality control tests of compounds used under similar road conditions as those for which the correlation was obtained. However, it must be remembered that the correlation holds in most cases only for a very narrow range of road testing conditions.

The tabular form of the correlation- and regression coefficient as function of log energy and log speed can also be shown as a three-dimensional graph, shown in figure 5, giving a quick

Figure 5: Correlation- and Regression Coefficients between Road- and Laboratory Test Wear Ratings as Function of log Energy and log Speed for Four Passenger tyre tread compounds



survey of useful testing conditions.

3. Results

3.1 The tyre test results

Table III shows the average test results for whole tyres on the drive axles of different types of

Table III: Road Wear Ratings of the 3 Basic Compounds on whole tyres

Compound	Road test conditions			
	rear drive tipper	front drive tipper	tractor units	rigids
1(NR/SBR)	100	100	100	100
2 (NR/BR)	113	105	127	126
3 (SBR/BR)	113	0	110	119

Table IV: Road Wear Ratings of the the three Basic Compoundson Tri-section Ttyres

Compound	Road test conditions		
	rear drive tipper	front drive tipper	tractor units
1(NR/SBR)	100	100	100
2 (NR/BR)	127	114	112
3 (SBR/BR)	113	-	110

vehicle. In each case tippers, tractor units and rigids were involved, between 4 and 7 vehicles. Because the vehicles varied in use the results varied to some degree with a standard deviation of approximately 11 points.

Table IV shows the results obtained with tri-section tyres for the three retread compounds involving polymers and table V shows the average ratings obtained for the seven compounds with the same base polymer but different types of filler. In each case different types of vehicle were involved.

3.2. The laboratory abrasion results.

Abrasion experiments were carried out according to the testing scheme described above on three Alumina surfaces of different coarseness.

Table V shows the record of an experiment at one testing condition with the seven

Table V: Road Wear Ratings of the Filler Compounds on Tri-section Tyres

Compound	Road test conditions			
	rear drive tipper	front drive tipper	tractor units	average
1	100	100	100	100
2	103	105	104	104
3	102	104	95	100
4	95	94	92	94
6	98	101	101	100
7	104	105	107	105
8	108	106	102	105

compounds containing different fillers. For the experimental design six different conditions were used and in each case four repeat measurements were carried out. The first table shows the abrasion loss as mg/km. The last column of this table shows the ratings of the compounds with compound 1 as reference.

The bottom row shows the average loss of all compounds. Ideally this should be constant, but because of environmental changes during the duration of the experiment small fluctuations are noticeable. The second table gives the side force coefficients from which the energy consumption is calculated according to the equation given above. The side force coefficient defined as side force/load (both in N) reflects both the stiffness of the compound and its friction coefficient. The third table shows the abrasion loss/unit energy dissipation. If the side force coefficient of an experimental compound is higher than that of the control, the rating improves. i.e. under equal slip conditions the compound with the higher side force (higher stiffness, and/or higher friction coefficient) is penalised compared with a softer one.

The last two tables indicate the estimated error for the difference between two compound ratings based on four repeat measurements for the abrasion and the side force measurements respectively.

With at least four, in this case six different testing conditions, the abrasion equation (4) quoted above can be solved and abrasion losses and relative compound ratings with one compound of the tested group set at 100 are obtained over a wide range of testing conditions Table VI shows the ratings obtained for compound 2 and 3 with compound 1 as the reference

Table VI: Compound Ratings of the Three Basic Compounds on Alumina 24 Laboratory Test

Compound 1 = 100

compound: 2

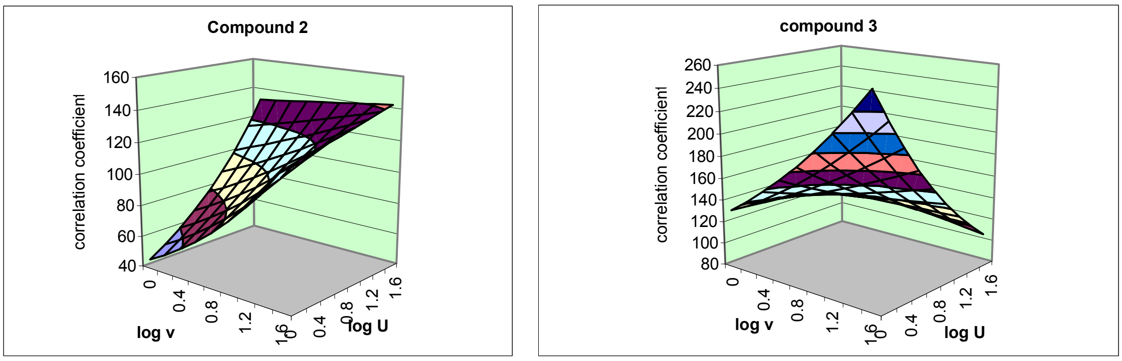
log U	log vf 0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
0	46.1	52.0	58.8	66.4	75.0	84.7	95.7	108.1	122.2
0.2	52.6	58.5	65.2	72.6	80.9	90.1	100.3	111.7	124.4
0.4	60.0	65.9	72.3	79.4	87.2	95.8	105.1	115.5	126.8
0.6	68.4	74.1	80.2	86.8	94.0	101.8	110.2	119.3	129.2
0.8	78.1	83.3	89.0	95.0	101.4	108.2	115.5	123.3	131.6
1	89.1	93.7	98.7	103.8	109.3	115.0	121.0	127.4	134.1
1.2	101.6	105.5	109.4	113.5	117.8	122.2	126.8	131.6	136.6
1.4	116.0	118.6	121.4	124.2	127.0	129.9	132.9	136.0	139.1
1.6	132.3	133.4	134.6	135.8	136.9	138.1	139.3	140.5	141.7

compound 3

log U	log vf 0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
0	132.6	144.3	157.0	170.8	185.8	202.1	219.9	239.2	260.2
0.2	131.5	141.1	151.5	162.7	174.6	187.5	201.3	216.1	231.9
0.4	130.4	138.1	146.3	155.0	164.2	173.9	184.2	195.1	206.7
0.6	129.2	135.1	141.2	147.6	154.3	161.3	168.6	176.3	184.3
0.8	128.1	132.2	136.3	140.6	145.1	149.6	154.3	159.2	164.2
1	127.1	129.3	131.6	134.0	136.4	138.8	141.3	143.8	146.4
1.2	126.0	126.5	127.1	127.6	128.2	128.8	129.3	129.9	130.5
1.4	124.9	123.8	122.7	121.6	120.5	119.4	118.4	117.3	116.3
1.6	123.8	121.1	118.4	115.8	113.3	110.8	108.3	106.0	103.6

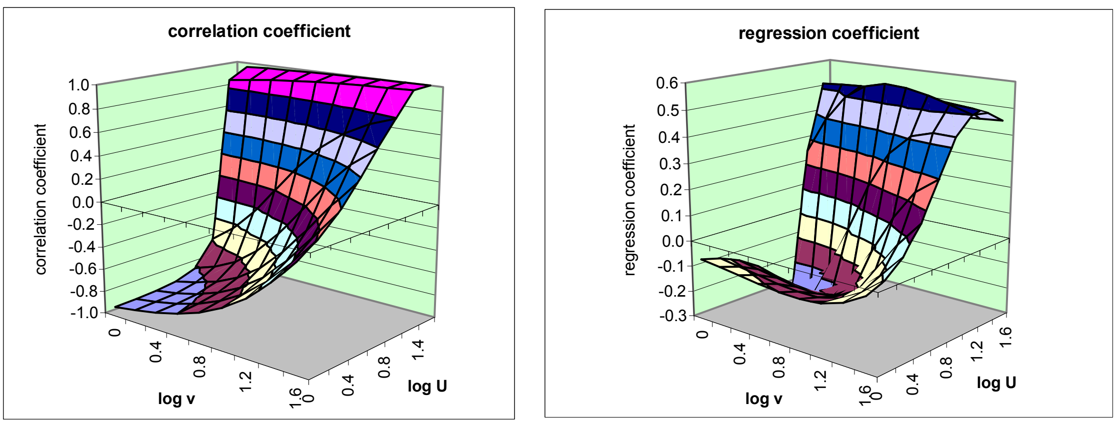
on Alumina 24. Both are better than the reference compound. Over a wide range of testing conditions. However, compound 2 behaves entirely differently to compound 3. Whilst at low energies and low speeds compound 2 is even inferior to compound 1 and is only marginally better at higher speeds, compound 3 is better than compound 1 in this range and therefore much better than compound 2. With increasing energies compound 2 becomes steadily better whilst the advantage of compound 3 decreases. At the highest level of energies and speeds compound 3 is only just as good as the control, whilst now compound 2 fares far better. Between 100 to 150 the ratings have been marked with different colours in steps of ten to bring out this fact more clearly. A three dimensional graph of the ratings of compound 2 and 3, shown in figure 6 also demonstrates the different behaviour of the two compounds clearly.

Figure 6: Laboratory Abrasion Rating of Compound 2 and 3 with Compound 1 as Reference (=100) as Function of log Energy and log Speed



Applying the correlation analysis described above to the laboratory- and road test results, the correlation coefficient can be plotted as a 3-dimensional graph as function of log energy and log speed. Figure 7 shows such a graph for the three basic compounds on tyres mounted on

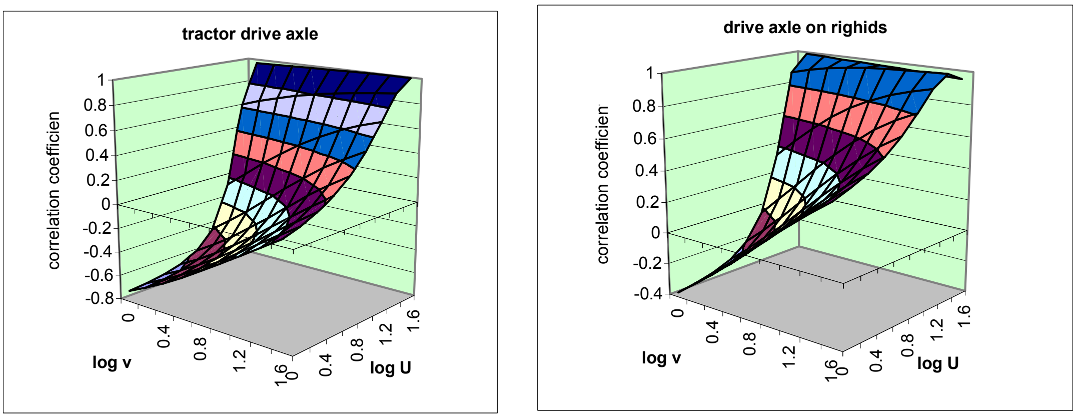
Figure 7: Correlation between Laboratory Abrasion on Alumina 24 and Road Wear Ratings on 1st Drive axle of Tippers - Three Basic compounds on whole tyres



the rear drive axles of tippers. It is seen that a high positive correlation is obtained at high energy levels i.e. at a range where compound 2 becomes good and compound 3 is not yet below the control. Figure 7 gives also the regression coefficient as function of log energy and log speed. The regression coefficient is always smaller than 1, indicating that the spread of the compound ratings in the laboratory is larger than is observed on the road. Therefore, if a compound developer wants to have an assured 10% improvement on the road, he should aim for at least 20% in the laboratory over a considerable range of energies and speeds.

Similar charts are obtained for the other uses ,tractor drive axles and the drive axles of rigid vehicles, too, as shown in figure 8 for the correlation coefficient obtained between laboratory

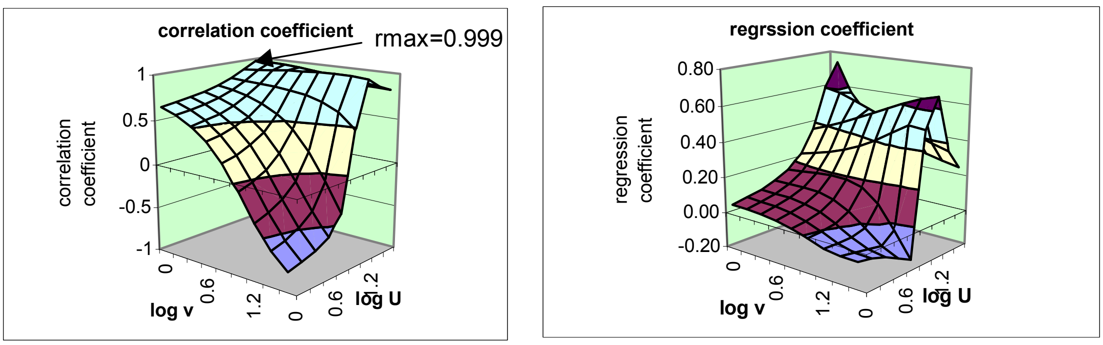
Figure 8: Correlation Coefficients betw.Road Wear Ratings on Tractor and rigids drive axles and Laboratory Abrasion on Alumina 24; Three basic compounds on whole Tyres



abrasion and the road use on tractor- and rigid drive axles respectively.

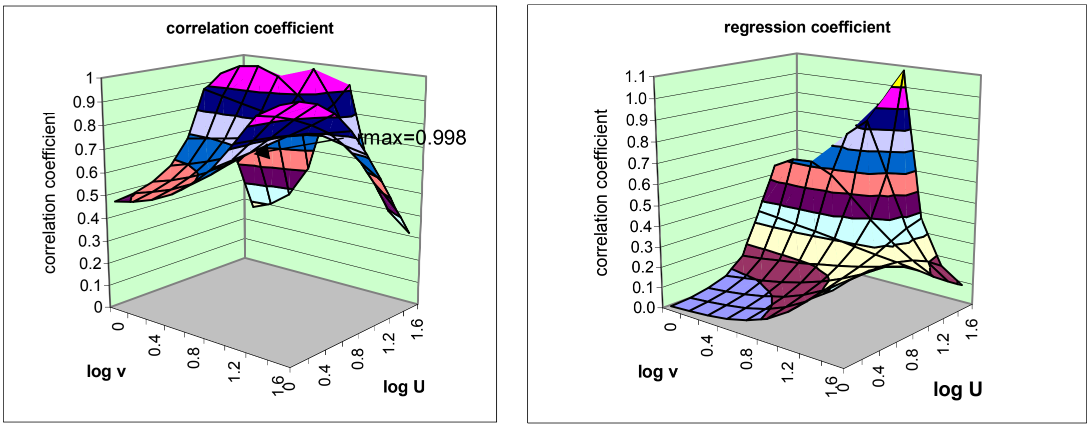
Laboratory experiments were also carried out on Alumina surfaces with finer grain sizes,

Figure 9: Correlation between Road Wear- and Laboratory Ratings on *Alumina 60.-* Three Basic Compounds on Whole Tyres



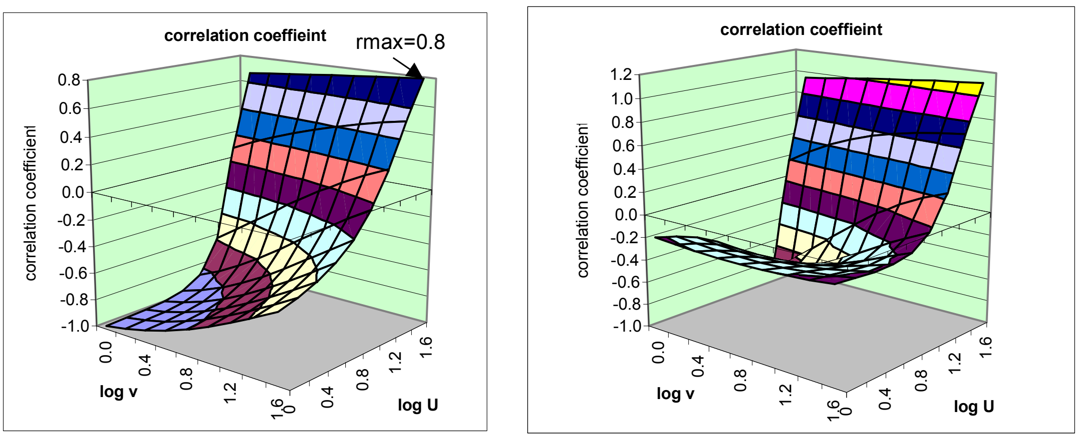
namely 60 and 120. The correlation and regression coefficients are shown in figures 9 and 10 between the laboratory abrasion and the road wear for whole tyres on the rear drive axle of tipper vehicles. The correlation curves look very similar to those obtained for the laboratory abrasion on Alumina 24. This shows that the grain size of the abrasive disk does not play an

Figure 10: Correlation between Road Wear- and Laboratory Ratings on Alumina 120:



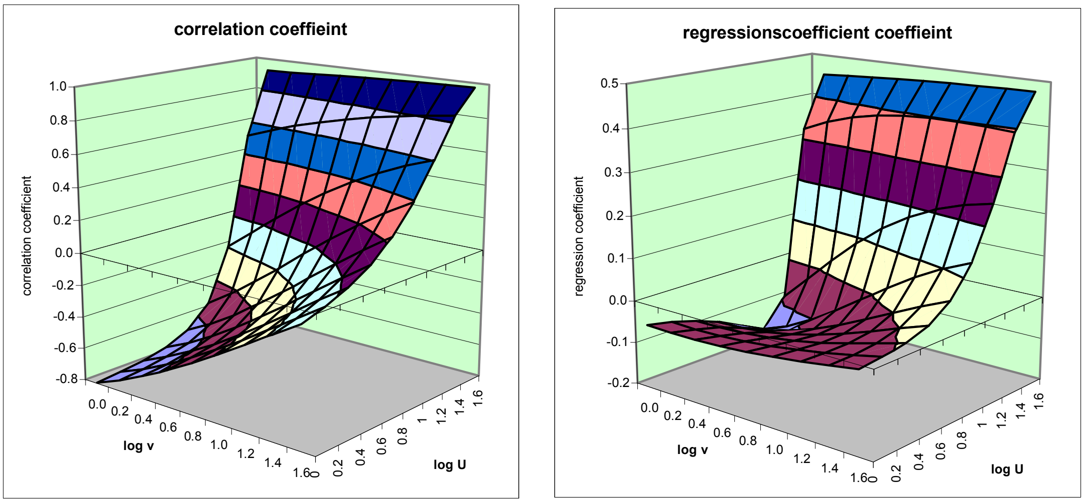
essential part when comparing laboratory abrasion with road wear. For practical reasons it is more convenient to use the coarser disks i.e. 60 or 24 mesh size, since these disks do not clog up with the dust and abrasion particles even over prolonged periods of abrasion experiments. In all cases, the good correlation is only obtained at high energy levels. At low energy levels the correlation can even become negative This means a reversal in ranking between road wear and laboratory abrasion, showing the complex relation between these two processes. In the present case the correlation did not depend strongly on speed. Hence the laboratory effort could be reduced by carrying out the abrasion experiments only at one speed but different energy levels i.e. different slip angles and/or loads. It must, however be pointed out that this leads to a loss of information and hence to a certain degree of uncertainty (In many cases the speed dependence of compounds is large enough to lead to reversals in ranking).

Fig 11: Correlation between Road Wear- and Laboratory Ratings on Alumina 24 - Three Basic Compounds on Tri-section Tyres on Tipper Rear Drive Axles



Figures 11 and 12 show the correlation- and regression coefficients between road wear and laboratory abrasion for the three basic compounds on tri-section tyres on rear drive tipper axles and on the drive axles of tractor units. The correlation is good only at the highest energy

Fig 12: Correlation between Road Wear- and Laboratory Ratings on Alumina 24
Three Basic Compounds on Tri-section Tyres on Tractor Drive Axles



levels and in case of the tipper not as good as for the whole tyre experiments. The reason is that compound 3 fares much poorer under these conditions on the road than for the whole tyre experiments. This is probably not due to a poorer compound 3 but rather due to the mounting of three compounds on the same carcass. Compound 3 is harder than compound 2 or compound 1. The force on the axle is an average for the three compounds resulting also in an average slip. The harder compound takes more of the average force than the softer ones. The average slip is also larger for the harder compound than it would be if it were mounted whole on the same tyre. Hence it consumes more energy than it would as a whole tyre, whilst the softer compounds consume less.. Hence the harder compound wears more and the softer one less than they would if they were mounted as whole tyres.

Figure 13: Correlation between Laboratory Tests on Aumina 24 and Road Tests Tipper Rear Drive Axle - Seven Filler Compounds on Tri-Section Tyres

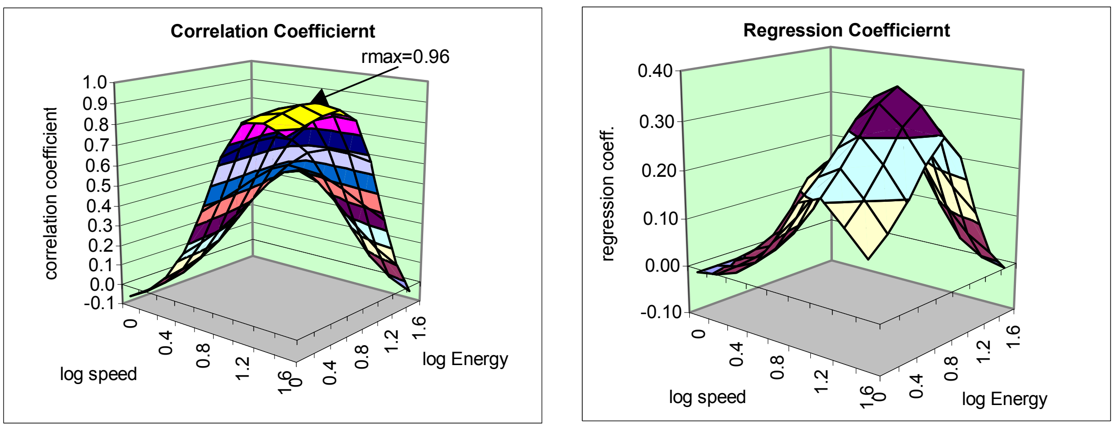
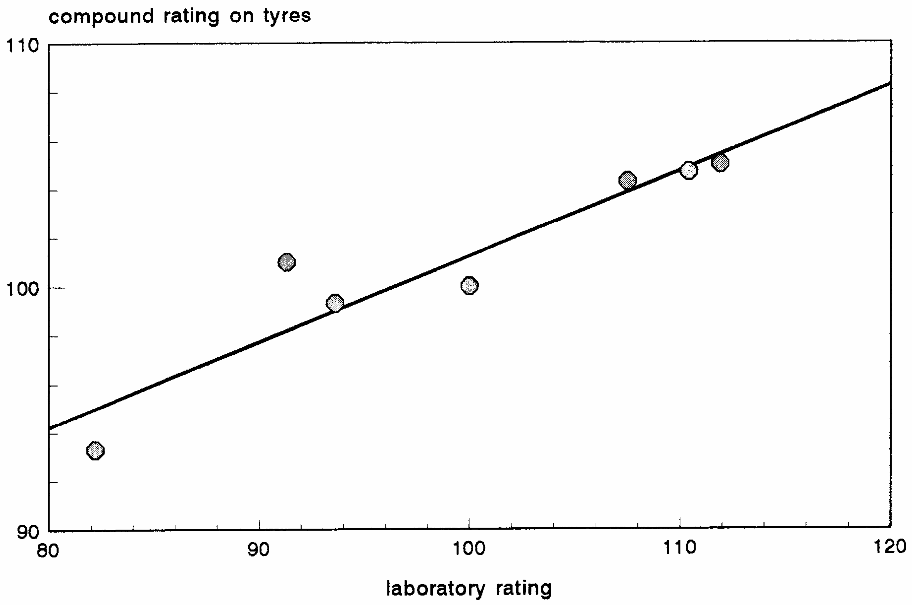


Figure 13 shows the correlation- and regression coefficients of the tri-section tyre experiment in which seven compounds containing the same base polymer but different types of filler were used. The range of high correlation is much smaller and is limited both for energy and speed.

Again the regression coefficients are smaller than 1 indicating that the laboratory experiments show a larger spread than the road use. This is also true for the other uses on tractor- and rigids drive axles. Figure 14 shows the actual correlation between road wear rating and

Figure 14: Cerrelation between the Average Rating of Multi-section Tires and Laboratory Ratings at an Energy Level of 4.0 kJ/km and a Laboratory Speed of 15.8 km/h 7 Filler compounds



laboratory rating for the test condition of highest correlation.

All correlation coefficients, regression coefficients and testing conditions for all experiments carried out during the EU Craft project are shown in table VII. A high correlation at a particular testing condition would suggest that such correlations could always be achieved if this single testing condition would be used. The table shows, however, that the conditions of highest correlation do change with the use of the tyre for a particular abrasive disk. Obviously, the best information is obtained if the whole experimental design is carried out. The strength and weakness of a compound in relation to a known control are clearly brought out.

4. Conclusion

The complexity of the wear behaviour of thread compounds under different service conditions requires an experimental design of laboratory testing conditions in order to be able to foresee all eventualities. The basis of such a design is the known dependence of the abrasion on energy consumption and slip speed in the contact area. To be able to carry out such a scheme the apparatus must both be able to measure the energy consumption at any testing condition as well as realise a wide range of energy and speed conditions.

With such a scheme it was possible to obtain a high correlation between laboratory abrasion and road wear ratings in all cases. However, it is also clear from the above findings that single point measurements have very little chance to succeed in obtaining a good correlation between laboratory ratings and road wear tests. The totally different behaviour of basic compound 2 and 3 in relation to the control compound 1 as function of energy and speed alone is sufficient to make it very difficult to find such a correlation with a single point measurement. Even if such a condition had been found by chance, it would yield no information on the hazards in store if the use of the compound were to be changed. Admittedly, the experimental design proposed here requires a certain amount of effort. The reward, however, is a detailed knowledge of the wear behaviour over a wide range of different uses from mild passenger tyre conditions to very severe heavy service tyre employment, a knowledge which could never be realised in direct road testing. Even a single point road testing result is very much more expensive than the most thorough laboratory abrasion experimental design.

Acknowledgements

The authors wish to express their appreciation to J. O'Connell, prime proposer of the BRITE EURAM contract n°: BRST – CT96 - 5077, to its members for their contribution and to the European Commission for supporting this project.

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