The Use of Novel Parameters in the Assessment of Natural Rubber Processability

G.M. BRISTOW* AND A.G. SEARS*

A number of parameters related to rheological behaviour of natural rubber (NR) may be obtained from unconventional measurements using the Mooney viscometer. These parameters have been measured on commercial samples of the major available grades of SMR. Discrimination between grades is better than for more conventional parameters. The significance of the measurements in terms of consistent processability of NR is discussed.

Technically specified rubber (TSR) was first introduced by Malaysia under the Standard Malaysian Rubber (SMR) Scheme, and its characteristics and advantages are now familiar to all NR consumers. Marketed in polyethylene-wrapped bales packaged in unit containers, SMR conforms to technical, rather than visual, specifications. Levels or ranges of ash, nitrogen, dirt, volatile matter, plasticity (P_0) and resistance to oxidative breakdown (PRI) are guaranteed. Similar schemes, with a number of differences, are operated by other NR producing territories. The SMR Scheme provides additional information on cure rate for latex grades, and two viscosity-stabilised grades, SMR CV and SMR GP, are produced to declared ranges of Mooney viscosity.

Over the last few years, consumers have increasingly emphasised the need for improved consistency in processing behaviour of both natural and synthetic rubbers. Many of the parameters specified in the current SMR Scheme relate more to the purity of the rubber than to its processability. Only the information on Mooney viscosity provided for SMR CV and SMR GP and the P_0 and PRI values for all grades relate directly to processability. A further factor often overlooked is the grade effect: the source materials and production route used have a considerable influence so that, for example, SMR L differs characteristically in processability from SMR 20. The customary selection of a single SMR grade for a given application automatically imposes some constraint on processing behaviour. However, there is growing need for processability parameters suitable for inclusion in the SMR Scheme. Such parameters should ideally be obtained from well-proven and generally-available instruments known to be suitable for use under quality control conditions rather than from sophisticated and expensive 'processability testers', though the latter may give data which are more readily interpreted in terms of rheology. Also, unless the consumer is prepared to accept the producers' assessment of processability, whether expressed numerically or in terms of sub-grades, there must be agreement on test procedures and knowledge of testing errors. This is more readily achieved for well-tried and generally-available equipment.

Attention has recently been drawn to the potential use of the Brabender *Plasticorder* to assess susceptibility to mechano-chemical breakdown, which is a major factor in the processing behaviour of natural rubber[1]. A processability specification based upon the use of this instrument may be possible but little information on this has yet been published. The *Plasticorder*, or a more recently developed processability tester, may ultimately give the best approach to the production of NR having consistent processing behaviour. Nevertheless, it seems desirable that the maximum information should be obtained from equipment already in use, even if this involves the use of non-

*Malaysian Rubber Producers' Research Association, Brickendonbury, Hertford SG13 8NL, United Kingdom

standard test procedures. In this context it is important to note that there is no *necessity* for a processability test to predict particular aspects of processing behaviour since the basic aim is only to provide raw NR which behaves consistently when processed by the consumer.

As noted above, NR grade, or more correctly source material and production procedure, are in fact parameters affecting processability. This is, of course, recognised by consumers and such differences in processability are probably partly the basis of the long-standing controversy over the relative merits of sheet and crumb rubber. For the producer, the knowledge that inadvertent variations in procedure during rubber production result in changes in processability may inhibit deliberate changes aimed at improving product quality or production economics. A good example of this is seen in the coagulation of latex by heat gelation rather than acidification to give a latex quality rubber which, in terms of processability, is manifestly not SMR L[2].

In the longer term, a fully technical SMR Scheme can be envisaged where all reference to source material and production procedure is replaced by specified parameters. This paper presents an evaluation of the information on processability given by non-standard procedures using the Mooney viscometer, and analyses the data in terms of possible contributions to a processability specification.

EXPERIMENTAL

Materials

Fifteen to twenty samples of each of the current major SMR grades were obtained from typical commercial production of different SMR factories. The data obtained therefore give some indication of the expected within-grade variability for each grade. Before use, all samples were blended on a 300 × 150 mm two-roll mill. The SMR test procedure[3] was used, *i.e.* six passes with a nip setting of 1.65 mm, but with a roll temperature of 40°C rather than 'ambient temperature (with water cooling)' as specified (See *Appendix*).

Wallace plasticity measurements. Wallace plasticity values, P_0, were determined using the Plastimeter under the conditions specified for SMR testing[3], except that the required smooth sheet was prepared by three passes through mill rolls at 20°C rather than two passes through cool rolls. ISO 2390:1981 specifies three passes through mill rolls at ambient temperature (See *Appendix*).

Mooney viscometer measurements. A range of 'non-standard' parameters was obtained using the Mooney viscometer at 100°C. In the standard ML 1 + 4 test, initial maximum torque, ML_{max}, was recorded as well as the normal reading at 4 minutes. As the rubber temperature after preheating for 1 min is still below 100°C, longer preheating reduces ML_{max} *(Figure 1)*. ML_{max} is essentially constant for preheat periods of 5 min or greater *(Figure 1)*, and 5 min preheat was therefore adopted for routine testing. As might be expected, the viscosity value after 4 min is far less dependent on preheat time over the same range.

A further feature of the torque *versus* time relation observed with the Mooney viscometer is shown in *Figure 2*. The torque often falls from the initial maximum before rising to the 'equilibrium value' at *ca.* 4 minutes. The exact minimum torque value is rather difficult to determine; as a compromise the value of the torque at 1 min, *i.e.* ML'1 = ML 5 + 1, was recorded.

While the torque observed after 4 min is normally considered to be the characteristic 'viscosity' of the rubber, it is not in fact an equilibrium value as, owing to chemical (oxidative) and/or rheological factors, the torque decreases more or less slowly after this time. The rate of this decrease was characterised in a ML 5 + 60 test by the values of the ML 5-ML 60 and ML 10-ML 60.

The relaxation of torque following cessation of rotor movement, first studied by Mooney[4] and later considered by Blow[5] as a means of characterising GR-S, was also studied. On completion of a ML 5 + 4 measurement the rotor drive was switched off and torque recorded every 10 s for 90 seconds. The data
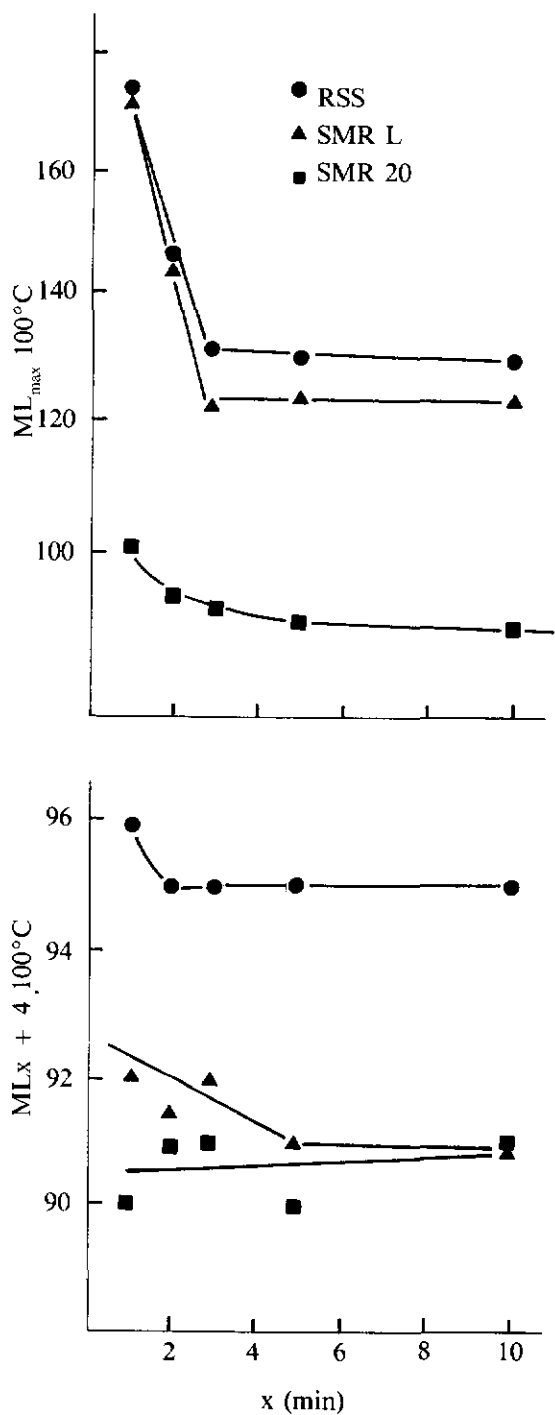
16

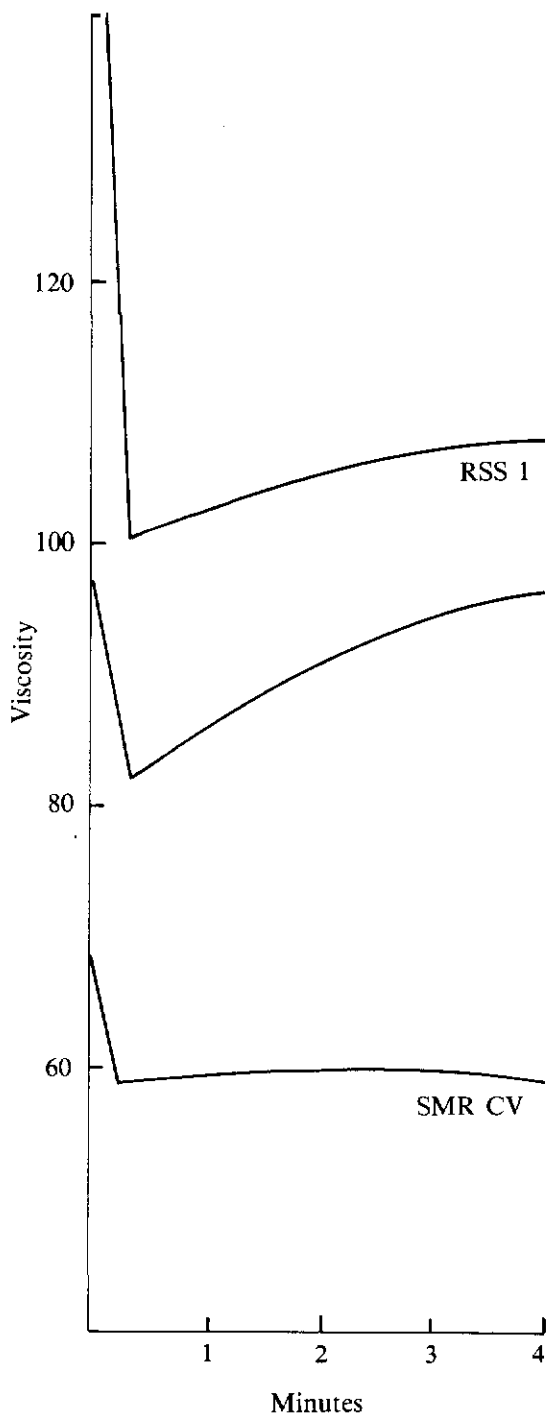*Figure 1. Dependence of initial maximum and 4-min viscosity on preheat time.*

Figure 2. Typical torque/time relations observed with the Mooney viscometer.

obtained were found to conform to the relation

$$torque = kt^{-a}$$

where k = torque after relaxation for 1 second. A parameter based on k or, more significantly, on the rate of relaxation a can therefore be obtained. However, the form of the expression makes k and, particularly, a rather sensitive to timing errors, especially to systematic errors arising from imprecision in timing the start of relaxation. For example, an observed relationship

$$torque = 99.3t^{-0.224}$$

becomes

$$torque = 103.2t^{-0.233}$$

or

$$torque = 95.5t^{-0.215}$$

if undetected systematic timing errors of + 1 s or − 1 s, respectively, are present. The relaxation has therefore also been characterised more simply by the change in torque after fixed times of relaxation,

D_1 = torque at 4 min − torque after 20 s relaxation

D_2 = torque at 4 min − torque after 90 s relaxation.

The test procedures, test data recorded and parameters utilised are summarised in *Table 1*. Details of within-sample reproducibility, *i.e.* experimental error, are given in *Table 2*.

RESULTS

Table 3 gives data for the existing tests for processability in the SMR Scheme: ML 1 + 4, 100°C; P_0; and PRI.

Grade mean values and standard deviations for the application of the test procedures summarised in *Table 1* are given in *Tables 4–10*. In view of disparities in the number of samples of each grade and in particular of the extent to

TABLE 1. SUMMARY OF TEST MEASUREMENTS AND DERIVED PARAMETERS

Test	Value measured	Derived parameters
ML 1 + 4, 100°C	Maximum viscosity, ML_{max}	ML_{max}–ML 4
	Viscosity at 4 min, ML 4	ML_{max}/ML 4
		ML 4/P_0
ML 5 + 4, 100°C	Maximum viscosity, ML'_{max}	ML'_{max}–ML'4
	Viscosity at 1 min, ML'1	ML'_{max}/ML'4
	Viscosity at 4 min, ML'4	ML'4–ML'1
	Torque after 20 s relaxation, ML_R20	k (see text)
	Torque after 90 s relaxation, ML_R90	a (see text)
		a (ML'4) (see text)
		D_1 (see text)
		D_3 (see text)
		ML'_{max}/P_0
		ML'4/P_0
ML 5 + 60, 100°C	Viscosity at 5 min, ML 5	ML 5–ML 60
	Viscosity at 10 min, ML 10	ML 10–ML 60
	Viscosity at 60 min, ML 60	

TABLE 2A. REPRODUCIBILITY OF TESTING:
WALLACE PLASTICITY (FIVE TEST PIECES FROM
A SINGLE SHEET)

Grade	Initial plasticity, P_0		
	Mean	sd	CV (%)
SMR L	60.4	0.9	1.5
SMR 20	52.6	1.3	2.6

which the samples are sufficiently representative of the grade, the significance of the between-grade difference has not been assessed by variance analysis. As an alternative and admittedly very approximate arbiter, the maximum difference in grade means has been compared with the typical or average scatter within a grade. Such comparisons are included for each parameter in *Tables 4–10*.

Comparison of maximum and 4-min viscosities (Tables 4 and 5). Since maximum viscosity will clearly depend on the value at 4 min, the data are assessed as the difference and as the ratio of these values. The latter apparently gives less within-grade scatter. Maximum viscosity is relatively high for the latex grades, and as expected, the effect is greater in absolute terms for the ML 1 + 4 test *(Table 4)* than for ML 5 + 4 *(Table 5)*. However, discrimination between the grades, especially between the several latex grades, is greater for the parameters based upon ML 5 + 4.

Relation between P_0 and Mooney viscosity (Table 6). In terms of experimental procedure, P_0 is more akin to maximum viscosity than to the value after 4 minutes. It is not surprising therefore that relatively low values of ML $4/P_0$ and ML'$4/P_0$ are associated with latex grades and that ML'$_{max}/P_0$ does not discriminate between grades. Again, as might

TABLE 2B. REPRODUCIBILITY OF TESTING: MOONEY VISCOMETRY
(FIVE TESTS ON A SINGLE BLENDED SAMPLE)

Parameter	RSS			SMR 20			SMR 10		
	Mean	sd	CV (%)	Mean	sd	CV (%)	Mean	sd	CV (%)
ML'$_{max}$	145.2	1.5	1.0	100.6	1.1	1.1	—	—	—
ML'1	102.1	0.7	0.6	90.9	0.4	0.5	—	—	—
ML'4	104.1	0.2	0.2	94.6	0.5	0.6	—	—	—
ML'$_{max}$–ML'4	41.1	1.4	3.5	6.0	1.2	20.4	—	—	—
ML'$_{max}$/ML'4	1.394	0.011	0.8	1.063	0.013	1.2	—	—	—
ML'4–ML'1	2.0	0.6	30.6	3.7	0.6	15.4	—	—	—
ML$_R$20	60.3	1.1	1.8	42.6	0.5	1.3	—	—	—
ML$_R$90	46.3	0.6	1.2	28.8	0.4	1.6	—	—	—
D_1	43.8	1.2	2.6	52.0	1.0	1.9	—	—	—
D_2	57.8	0.6	1.0	65.8	0.8	1.3	—	—	—
k	101.4	1.5	1.5	91.7	2.5	2.7	—	—	—
a	0.176	0.004	2.4	0.256	0.007	2.9	—	—	—
ML 5	103.4	0.5	0.5	—	—	—	86.6	0.5	0.6
ML 10	101.3	0.3	0.3	—	—	—	84.3	0.4	0.5
ML 60	101.3	2.0	2.0	—	—	—	66.4	0.4	0.6
ML 5–ML 60	2.1	1.8	84.9	—	—	—	20.2	0.6	2.8
ML 10–ML 60	0.0	1.7	—	—	—	—	17.9	0.2	1.2

TABLE 3. CONVENTIONAL PROCESSABILITY PARAMETERS

Grade	No. of samples	ML 1 + 4, 100°C			P_0			PRI		
		Mean	sd	CV (%)	Mean	sd	CV (%)	Mean	sd	CV (%)
SMR 5	17	96.0	4.7	4.9	50.6	6.4	12.7	74.1	4.9	6.6
SMR 10	17	94.9	3.4	3.5	46.5	3.2	7.0	66.5	6.6	9.9
SMR 20	19	89.7	8.3	9.2	44.3	5.9	13.4	67.5	8.8	13.0
SMR CV	21	64.4	4.6	7.1	34.0	2.7	8.0	83.8	5.5	6.6
SMR WF/L	18	90.3	7.1	7.8	53.5	4.0	7.4	80.0	4.8	6.0
RSS	10	90.8	4.5	4.9	58.6	4.1	7.1	78.8	4.2	5.3

TABLE 4. PARAMETERS DERIVED FROM ML_{max} AND ML 4

Grade	No. of samples	ML_{max}–ML 4			ML_{max}/ML 4		
		Mean	sd	CV (%)	Mean	sd	CV (%)
SMR 5	17	49.3	29.1	59	1.512	0.303	20
SMR 10	17	25.7	10.3	40	1.270	0.105	8
SMR 20	19	27.2	15.2	56	1.299	0.152	12
SMR CV	21	26.5	6.3	24	1.415	0.103	7
SMR L/WF	18	64.6	17.1	27	1.713	0.174	10
RSS	10	64.8	15.8	24	1.175	0.177	10
Average sd of grade means, S		15.6			0.169		
Max difference in grade means, Δ		39.1			0.445		
S/Δ		2.5			2.6		

TABLE 5. PARAMETERS DERIVED FROM ML'_{max} AND ML'4

Grade	No. of samples	ML'_{max}–ML'4			ML'_{max}/ML'4		
		Mean	sd	CV (%)	Mean	sd	CV (%)
SMR 5	17	10.6	10.2	96	1.110	0.104	9
SMR 10	17	2.7	5.5	209	1.026	0.056	6
SMR 20	19	3.2	5.5	181	1.033	0.063	6
SMR CV	21	15.2	5.2	34	1.238	0.087	7
SMR L/WF	18	18.4	7.0	38	1.207	0.086	70
RSS	10	26.0	7.2	28	1.289	0.084	7
Average sd of grade means, S		6.8			0.080		
Max difference in grade means, Δ		22.8			0.2576		
S/Δ		2.5			2.6		

TABLE 6. RELATIONS BETWEEN P_0 AND MOONEY VISCOSITY

Grade	No. of samples	ML 4/P_0			ML'$_{max}$/P_0			ML'4/P_0		
		Mean	sd	CV (%)	Mean	sd	CV (%)	Mean	sd	CV (%)
SMR 5	17	1.92	0.21	11	2.13	0.08	4	1.94	0.20	10
SMR 10	17	2.05	0.11	5	2.12	0.09	4	2.07	0.12	6
SMR 20	19	2.04	0.13	6	2.12	0.07	3	2.05	0.13	6
SMR CV	21	1.90	0.13	7	2.36	0.07	3	1.91	0.15	8
SMR L/WF	18	1.69	0.09	5	2.04	0.12	6	1.70	0.09	5
RSS	10	1.56	0.09	6	1.99	0.09	5	1.55	0.09	6
Average sd of grade means, S		0.127			0.087			0.130		
Max difference in grade means, Δ		0.49			0.37			0.52		
S/Δ		3.9			4.3			4.0		

be anticipated, the time of preheat in the Mooney test is unimportant.

Short-time Mooney tests (Table 7). The rather more limited data for ML'4–ML'1 also show characteristic differences between latex and field coagulum grades. However, the absolute value of ML'4–ML'1 is rather small and the within-grade variation proportionately large, so that discrimination is poor. Further work is necessary to investigate the full potential of this procedure.

Extended Mooney viscosity tests (Table 8). One of the factors leading to a progressive decrease in torque over the period 5–60 min must be susceptibility to oxidative degradation, and a correlation between the extended test and PRI might be anticipated. As shown in *Figure 3*, such a correlation does exist if mean values for the various grades are considered, but the individual sample data show no correlation. The scatter is far greater than would be expected from the precision of the data *(cf. Table 2)* so that other factors must be involved. Once again there are clear indications of between-grade differences.

Relaxation tests (Tables 9 *and* 10*)*. Grade mean values for the relaxation rate parameter *a* are given in *Table 9*. Within-grade variability

TABLE 7. PARAMETERS FROM SHORT-TIME MOONEY TESTS, ML 5 + 4, 100°C

Grade	No. of samples	ML'4–ML'1		
		Mean	sd	CV (%)
SMR 5	8	+3.3	1.3	39
SMR 10	10	+4.5	1.8	41
SMR 20	10	+4.3	1.9	44
SMR CV	10	0.0	1.5	—
SMR L	10	+1.0	1.0	107
RSS	10	−1.2	1.8	153
Average sd of grade means, S		1.6		
Max difference in grade means, Δ		5.7		
S/Δ		3.6		

is relatively high; only for SMR CV and possibly RSS are there any indications of significant differences between the various grades. However, general experience of relaxation phenomena and tests with masticated rubbers *(Figure 4)* indicate that *a* is very dependent on the stress level before relaxation, *i.e.* the ML 5 + 4 value. The relatively high value of *a* for SMR CV is therefore probably associated

21

TABLE 8. VISCOSITY CHANGES IN EXTENDED MOONEY TEST, ML 5 + 60, 100°C

Grade	No. of samples	ML 5–ML 60			ML 10–ML 60		
		Mean	sd	CV (%)	Mean	sd	CV (%)
SMR 5	8	13.5	2.7	20	11.4	2.6	23
SMR 10	10	18.2	3.1	17	15.3	3.4	22
SMR 20	10	15.0	4.6	31	13.0	4.5	35
SMR CV	8	5.6	0.8	14	3.4	0.9	25
SMR L	10	9.5	1.6	17	8.3	2.0	24
RSS	10	7.4	1.7	23	5.7	2.2	39
Average sd of grade means, S		2.4			2.6		
Max difference in grade means, Δ		12.6			11.9		
S/Δ		5.3			6.0		

TABLE 9. MOONEY RELAXATION TEST, $ML_R 90$: ANALYSIS BY RELAXED TORQUE $= kt^{-a}$

Grade	No. of samples	a			a (ML'4)		
		Mean	sd	CV (%)	Mean	sd	CV (%)
SMR 5	17	0.242	0.045	19	23.3	3.1	14
SMR 10	17	0.246	0.023	9	23.5	1.7	7
SMR 20	19	0.276	0.049	18	24.5	2.3	10
SMR CV	21	0.356	0.034	10	23.0	2.0	9
SMR L/WF	18	0.259	0.030	12	23.3	1.7	8
RSS	10	0.200	0.016	8	18.1	1.5	8
Average sd of grade means, S		0.030			2.1		
Max difference in grade means, Δ		0.156			6.4		
S/Δ		5.2			3.0		

with the relatively low viscosity of the grade. This explanation is supported by the virtual identity of mean values of a (ML'4) for the other grades except RSS. It should be noted that this approach does *not* compensate for viscosity variation within a grade, since the coefficients of variation for a (ML'4) are not greatly less than those for a itself. Whether a or a (ML'4) is considered, RSS shows a lower relaxation rate.

Data for the assessment of relaxation directly by the decrease in viscosity are given in *Table 10*. SMR CV again shows a lesser extent of relaxation, though the effect is not so marked as with the a value. In this case no attempt was made to correct D_1 and D_2 for any dependence on initial stress. RSS again shows a lower relaxation rate, but the values of D_1 and D_2 appear less discriminating in this respect than a or, better, a (ML'4).

TABLE 10. MOONEY RELAXATION TEST, ML 5 + 4, 100°C: ANALYSIS BY D_1 = ML'4–ML$_R$20
AND D_2 = ML'4–ML$_R$90

Grade	No. of samples	D_1			D_2		
		Mean	sd	CV (%)	Mean	sd	CV (%)
SMR 5	10	49.7	2.5	5	64.2	2.4	4
SMR 10	13	49.7	1.5	3	63.6	1.6	3
SMR CV	15	43.1	2.0	5	52.1	2.4	5
SMR L	19	46.4	1.7	4	59.0	2.9	5
RSS	15	44.0	2.8	6	57.2	3.3	6
Average sd of grade means, S		2.1			2.5		
Max difference in grade means, Δ		6.6			12.1		
S/Δ		3.1			4.8		

TABLE 11. SUMMARY OF GRADE MEAN VALUES OF PROCESSABILITY PARAMETERS

Parameter	SMR CV	SMR L/WF	RSS	SMR 5	SMR 10	SMR 20
ML 1 + 4, 100°C	64.4	90.3	90.8	96.0	94.9	89.7
P_0	34.0	53.5	58.6	50.6	46.5	44.3
PRI	83.8	80.0	78.8	74.1	66.5	67.5
ML 1 + 4/P_0	1.90	1.69	1.56	1.92	2.05	2.04
ML'$_{max}$/ML'4	1.238	1.207	1.289	1.110	1.026	1.033
ML'4–ML'1	0.0	1.0	−1.2	3.3	4.5	4.3
ML 5–ML 60	5.6	9.5	7.4	13.5	18.2	15.0
a (ML'4)	23.0	23.3	18.1	23.3	23.5	24.5
D_2	52.1	59.0	57.2	64.2	63.6	—

TABLE 12. SUMMARY OF RELATIVE GRADE MEAN VALUES OF PROCESSABILITY PARAMETERS

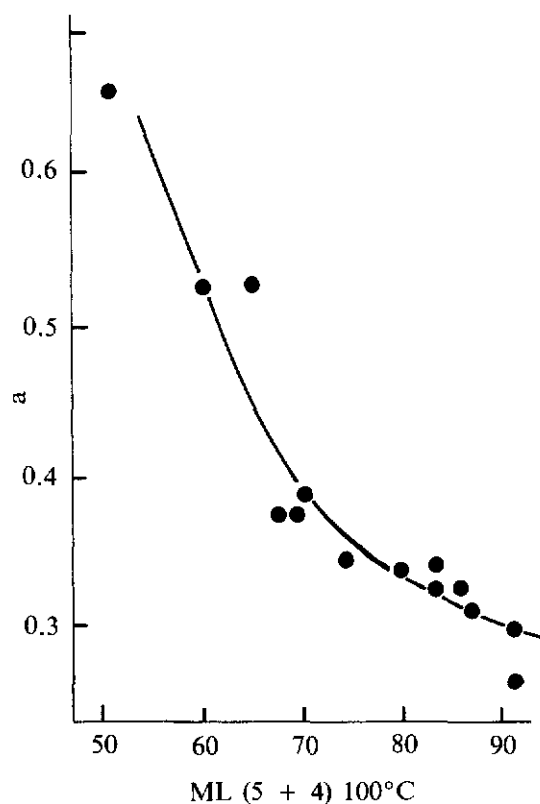| Parameter	SMR CV	SMR L/WF	RSS	SMR 5	SMR 10	SMR 20
ML 1 + 4	71	100	101	106	105	99
P_0	64	100	110	95	87	83
PRI	105	100	99	93	83	84
ML 1 + 4/P_0	112	100	92	114	121	121
ML'$_{max}$/ML'4	103	100	107	92	85	86
ML'4–ML'1	—	100	−120	330	450	430
ML 5– ML 60	59	100	78	142	192	158
a (ML'4)	99	100	78	100	101	105
D_2	88	100	97	109	108	—

Figure 4. Dependence of the relaxation parameters a on the degree of mastication of a sample of SMR 10.

CONCLUSIONS

Grade mean values for all the various test parameters are given in *Table 11* and summarised relative to the values for SMR L in *Table 12*. Of the conventional parameters, ML 1 + 4 or P_0 identify the low-viscosity, easy-processing quality of SMR CV, while PRI indicates the greater susceptibility to oxidative breakdown of SMR 10 and SMR 20. Most of the more novel parameters show greater discimination between grades. Tests of this type would identify the grade of, or perhaps more correctly the source material used for, a given sample of raw rubber, and go some way to eliminating the need for these factors to be detailed in SMR specifications. In this context it should perhaps be stressed that the samples studied were com-

Figure 3. Relation between PRI and torque change in the extended Mooney viscosity test.

mercial materials; while conforming to the SMR specifications they did not, with the possible exception of RSS, originate from rigidly controlled source materials and/or production procedures. Any variability in this respect would be a factor in the significant *within-grade* variability of most of the properties measured.

It is not suggested that any of the novel parameters identified here indicate any particular aspect of processability as it may be measured by the consumer. Indeed, this is not an essential requirement of a 'processability parameter': uniform processing in the consumer's factory must depend on consistent rheological behaviour from the NR, and the need is for a parameter which, directly or indirectly, measures this consistency in a reliable and reproducible way. Despite such considerations, it should be noted however, that recent attempts to interpret consumer problems with

NR have shown $ML'_{max}/ML'4$ and $ML'4/P_0$ to be the parameters of greatest utility.

REFERENCES

1. ONG, E.L. AND LIM, C.L. (1985) Brabender Plasticorder and Breakdown Index. *Proc. SMR Revision Wkshop Kuala Lumpur 1985.*

2. CHEONG, S.F. AND LIM, F.P. (1976) Continuous Heat Gelation of Latex — a Potentially Cost-effective Processing Technique for SMR. *Proc. Int. Rubb. Conf. 1975 Kuala Lumpur,* **IV**, 295.

3. RUBBER RESEARCH INSTITUTE OF MALAYSIA (1973) RRIM Test Methods for Standard Malaysian Rubbers. *SMR Bull. No. 7.*

4. MOONEY, M. (1934) A Shearing Disk Plastometer for Unvulcanized Rubber. *Ind. Eng. Chem. (Analyt.),* **6**, 147.

5. BLOW, C.M. AND SCHOFIELD, J.R. (1950) The Measurement of Stress Relaxation of Unvulcanized Rubber by Means of the Mooney Shearing-disc Viscometer. *Rubb. Chem. Technol.,* **23**, 601.

APPENDIX

Conditions specified for the preparation of rubber samples for SMR viscosity and plasticity tests are imprecise, particularly in respect of mill roll temperatures. In practice, ML 1 + 4, 100°C and P_0 are little affected by variations in roll temperature in initial blending *(Table A1)*

or in sheeting for Wallace plasticity tests *(Table A2)*. The effect of P_0 on three rather than two mill passes in the sheeting operation is hardly greater than the expected experimental error *(Table A3)*.

TABLE A1. MOONEY VISCOSITY AS A FUNCTION OF BLENDING TEMPERATURE
Blend procedure: 300 × 150 mm mill; nip 1.65 mm; six passes
Viscosity: four tests per batch

Roll temperature (°C)	Mooney viscosity, ML 1 + 4, 100°C				Mean
20	88	87	88	85	87.0
30	87	83.5	85	86.5	85.5
34	85	87.5	85	86	85.9
43	86	84	83	86	84.8
52	84.5	84	83	84	83.9
63	83	85	84	87	84.8

Variance analysis, all data: F ratio 2.49, significant at 90%-95%.

If data for 20°C omitted: F ratio 1.3, not significant at 99%.

TABLE A2. EFFECT OF MILL ROLL TEMPERATURE ON INITIAL WALLACE PLASTICITY
Blend procedure: 300 × 150 mm mill; three passes
Viscosity: ten test pieces per sheet or three test pieces selected at random

Roll temperature (°C)	Wallace plasticity P_0							
	SMR L				SMR 20			
	10 tests		3 tests		10 tests		3 tests	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd
21	60.7	1.1	61.3	0.6	52.8	1.2	52.0	1.7
30	59.7	1.3	59.0	1.0	53.6	0.8	53.7	0.6
41	62.0	0.8	61.3	1.1	52.4	1.1	53.0	0
49	59.9	0.9	60.3	0.6	51.6	0.8	51.0	1.0

TABLE A3. EFFECT OF NUMBER OF MILL PASSES ON INITIAL WALLACE PLASTICITY
Blend procedure: 300 × 150 mm mill, roll temperature 20°C
Viscosity: ten test pieces per sheet or three test pieces selected at random.

Mill passes	Wallace plasticity P_0							
	SMR L				SMR 20			
	10 tests		3 tests		10 tests		3 tests	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd
1	65.1	2.3	63.3	0.6	61.4	2.1	62.3	1.2
2	60.7	1.1	59.8	1.3	55.0	1.7	54.7	2.1
3	59.9	1.3	59.8	1.9	53.2	0.7	53.7	0.6
4	58.0	0.8	58.0	1.0	50.1	1.0	50.2	0.7
5	55.9	1.3	56.0	1.0	48.0	0.8	47.8	0.8