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Clonal Characterisation of Latex and Rubber Properties

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Properties of latex and bulk rubber from Hevea *clones of commercial interest have been studied. These include the* Class I, Class II *and some new* Class IIIA *clones described in the Rubber Research Institute of Malaysia (RRIM) Planting Recommendations.*

Latices, collected under standard conditions from about 100 trees of each clone and processed into latex concentrates and bulk rubbers using a fixed procedure, were investigated. Clonal differences have been observed in almost all the properties examined. Possible influences of various latex components and other factors on the variability of some of the properties are discussed.

Generally, most clones produce latex concentrates with fairly good latex stability, although added soap is needed in some cases. The mechanical stability of a few unstable clones however remain low due to poor response to the soap treatment. All other properties tested meet the specifications for latex concentrate.

While the RRIM clones often yield rubbers with low to medium viscosities, those from the PB (Prang Besar) clones generally tend to be of relatively high viscosity. The inclusion of comparatively few rubber clones with low viscosity in the Recommendations is noted. Latices from all clones are suitable for commercial production of SMR non-viscosity-stabilised rubbers, while clones which can be processed into SMR CV60 grade without blending with other latices have been identified. Twenty-five clones have been observed to yield light-coloured rubbers consistently.

Good correlations are observed between Mooney viscosity and initial Wallace plasticity of both non-CV and CV rubbers of these clones. Their cure characteristics, such as the torque change (ΔT) and the relaxed modulus (MR100), are also significantly correlated.

In the general breeding and selection programme of *Hevea brasiliensis* clones, emphasis has always been placed on the high yielding capacity and good growth characteristics of the trees, as well as their resistance to leaf diseases and wind damage. However, a high yielding clone with vigorous growth does not always produce latex and rubber of suitable properties as desired by the producers. More emphasis is now being placed on the properties of the latex and rubber obtained from individual clones. Although information of this type had been reported earlier in the RRIM Planting Manual of 1965[1], it referred mainly to the older clones, many of which are no longer planted. Information on the modern clones is somewhat scattered.

The present work was therefore undertaken to study, on a laboratory scale, the properties of latices and rubbers from clones that are of current interest to the industry. The *Class I, Class II* and some new *Class IIIA* clones, as indicated in the RRIM Recommendations for conventional planting[2] were thus investigated. The properties examined included those of fresh field latex, latex concentrate and raw

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rubber, all of which are related to the specifications required for concentrate and dry rubber production.

Classification of Clones

According to the RRIM Recommendations for conventional planting, clones are classified based on the growth and yield characteristics of the trees:

Class I clones : High performance materials recommended for large-scale planting.

Class II clones : Promising materials, suitable for moderate-scale planting.

Class IIIA clones : Experimental materials planted up to 10 ha per clone.

Class IIIB clones : New materials planted in one-task-size blocks only, selections of which have only been tested in small-scale trials.

EXPERIMENTAL

All the clones studied are planted in the RRIM Experiment Station, Sungai Buloh. The trees were all on the ½S d/2 tapping system. They had not been stimulated nor subjected to any special fertilising practices. The parentage of each clone, its location and panel of tapping during the investigation are shown in *Table 1*.

Latices were collected and pooled from approximately 100 trees of each clone, lightly ammoniated (0.08% for preparation of bulk rubbers, 0.4% for latex concentrates) and brought back to the laboratory as soon as possible. Latex from each clone was then processed immediately into latex concentrate and dry rubber (both viscosity-stabilised and non-viscosity-stabilised). For each clone, a total of at least six cycles of sampling and testing were carried out over a period of one to two years for each of the properties examined. Results are expressed as means of all the values obtained in each case.

Dry Rubber Content of Field Latex

This was determined using the standard method[3] involving the coagulation of a known weight of a representative sample of latex, with dilute acetic acid and determining the weight of the sheeted coagulum after drying at 75°C.

Acetone Extraction of Total Solids Film

Total solids film, obtained by drying latex on glass plates at room temperature for 24 h, was cut into very small pieces and extracted using a Soxhlet extracter for 16 h. The acetone was removed and the extract dried and weighed[3].

Elemental Analysis

Chemical analyses of field latex, latex concentrate and dry rubber were carried out using the methods described in the 'Manual of Laboratory Methods for Chemical Analysis of *Hevea brasiliensis* Rubber' published by the RRIM[4]. Values are expressed as percentage of total solids, except for copper and manganese which are in parts per million (p.p.m.) in view of their very low levels.

Preparation and Testing of Latex Concentrate

This was prepared by centrifuging field latex containing about 0.4% ammonia in a latex separator to give a concentrate of approximately 60% dry rubber content, which was then preserved with 0.7% ammonia as a high-ammonia (HA) concentrate.

The mechanical stability time (MST), potassium hydroxide (KOH) number and volatile fatty acid (VFA) number were determined according to procedures set out in *ISO 35, ISO 127* and *ISO 506* respectively.

Preparation and Testing of Bulk Rubbers

The dry rubbers tested were prepared from field latices following the SMR procedures of coagulation using formic acid at pH 5–5.2, after which the coagula were crumbled and dried at 100°C. In the case of viscosity-

TABLE 1. PARENTAGE, LOCATION AND PANEL TAPPED DURING INVESTIGATION OF FORTY-THREE CLONES PLANTED AT THE RRIM EXPERIMENT STATION, SUNGAI BULOH

Clone	Parentage	Field planted	Panel tapped
Class I			
GT 1	Primary clone	54	BO-2
RRIM 600	Tjir 1 × PB 86	28	BI-1
RRIM 712	RRIM 605 × RRIM 71	28	BI-1
PR 255	Tjir 1 × PR 107	45B	BO-1
PR 261	Tjir 1 × PR 107	28	BO-2
PB 217	PB 5/51 × 6/9	45A	BO-2
Class II			
RRIM 623	PB 49 × Pil B 84	20C	BI-1
RRIM 628	Tjir 1 × RRIM 527	14B	BI-1
RRIM 701	44/553 × RRIM 501	28	BI-1
RRIM 703[a]	RRIM 600 × RRIM 500	68	BO-2
RRIM 725[b]	F × 25 (ill)	34	BO-2
RRIM 728	GT 1 × RRIM 623	34	BO-2
RRIM 729	RRIM 623 × FX 25	34	BO-2
RRIM 805	RRIM 628 (selfed)	60C	BO-1
RRIM 901	PB 5/51 × RRIM 600	45A	BO-2
RRIM 905	PB 5/51 × RRIM 600	45A	BO-2
PB 28/59	Primary clone	34	BO-2
PB 230[c]	PB 5/51 × PB 49	34	BO-2
PB 235	PB 5/51 × PB s/78	28	BI-1
PB 254	PB 5/51 × PB s/78	38	BO-2
PB 255	PB 5/51 × PB 32/36	27	BO-2
PB 260	PB 5/51 × PB 49	27	BO-2
PB 280	PBIG seedling	34	BO-2
RRIC 100	RRIC 52 × PB 86	45C	BO-1
RRIC 110	LCB 1320 × RRIC 7	45C	BO-1
IAN 873[b]	PB 86 × F 1717	38	BO-2
PM 10	Primary clone	60C	BO-1
BPM 24	GT 1 × AVROS 1734	45C	BO-1
Nab 17	Tjikadu seedling	35	BI-1
Class IIIA			
RRIM 709[c]	RRIM 605 × RRIM 71	28	BI-1
RRIM 710[c]	RRIM 605 × RRIM 71	28	BI-1
RRIM 717[c]	PB 49 × RRIM 603	27	BO-2
RRIM 730[c]	LCB 1320 × RRIM 623	34	BO-2
RRIM 803	RRIM 501 × RRIM 623	38	BO-2
RRIM 804	RRIM 501 × 44/553	38	BO-2
RRIM 806	RRIM 600 × RRIM 701	45C	BO-1
RRIM 809	RRIM 600 × RRIM 623	45C	BO-1
PB 242	PB 5/51 × PB 32/36	28	BI-1
PB 274	PB 28/59 × PB 32/36	38	BO-2
PB 312	RRIM 600 × PB 235	60C	BO-1
PM 8	Primary clone	60C	BO-1
RRIC 101	Ch 36 × RRIC 7	45C	BO-1
RRIC 102	RRIC 52 × RRIC 7	45C	BO-1

ill : Illegitimate

BO-1, BO-2 : Virgin panels

BI-1, BI-2 : Renewed panels

[a]Clone withdrawn from recommendation due to wind damage

[b]Clone withdrawn from recommendation due to Corynespora attack

[c]Clone withdrawn from recommendation due to poor yield

stabilised (CV) rubbers, 0.15 p.p.h.r. of hydroxylamine neutral sulphate (HNS) was added before coagulation.

Mooney viscosity *(V_R)*, Wallace plasticity *(P_o)*, Plasticity Retention Index (PRI), degree of storage hardening and colour were all determined using recommended methods[5].

The cure behaviour of each rubber was assessed by measuring the torque required to oscillate a biconical disc at an angle of ± 3° in the ACS 1 mix at 160°C, using a Monsanto rheometer, according to *ISO 3417*. The torque was recorded autographically as a function of time.

Assessment of cure characteristics was also done by determining the relaxed modulus at 100% extension (MR100) measured on test-pieces prepared using the ACS 1 mix, and vulcanised at 140°C for 40 min[5].

RESULTS AND DISCUSSION

Field Latex Properties

Hevea latex as obtained from the tree consists not only of rubber hydrocarbon particles, but also non-rubber substances which include lipids, proteins, carbohydrates, acids, amines and some inorganic constituents. It is generally known that some of these non-rubbers can affect the properties of latex concentrates and bulk rubber derived from the field latex. Relevant field latex properties such as dry rubber content (d.r.c.), acetone soluble-non-rubber content (acetone extract) and elemental composition were therefore investigated. Results for the various clones studied are as shown in *Tables 2* and *3*.

Dry rubber content. This is a highly variable property. When a tree of any one clone or seedling is first tapped, it produces an unstable

TABLE 2. DRY RUBBER CONTENT OF FRESH *HEVEA* LATEX FROM CLASS I, CLASS II AND CLASS III CLONES

Class	D.r.c. of fresh *Hevea* latex			
	Below average 31%–34%	Average 34%–38%	Above average 38%–41%	High > 41%
I	—	GT 1	PR 255	—
		RRIM 600	PR 261	
		RRIM 712	PB 217	
II	—	RRIM 725	RRIM 701	RRIM 623
		RRIM 728	RRIM 703	RRIM 628
		RRIM 729	RRIM 905	RRIM 901
		RRIM 805	PB 230	PB 28/59
		IAN 873	PB 255	PB 235
			PB 260	PB 254
			RRIC 100	PB 280
			BPM 24	RRIC 110
			Nab 17	PM 10
III A	*RRIM 710*	RRIM 709	RRIM 717	RRIM 730
	PB 274	RRIM 804	RRIM 803	
		RRIM 806	PB 242	
		RRIM 809	RRIC 102	
		PB 312		
		PM 8		
		RRIC 101		

latex with a high rubber content. As the tapping is continued with a regular tapping system, the latex stability increases and the d.r.c. falls to a steady level which can vary between 25% and 45%, depending on the nature of the planting material. Changes in d.r.c. can also be brought about by other factors such as the tapping system, seasonal variation and yield stimulation[6,7,8]. For example, a full-spiral cut gives a lower d.r.c. than a half-spiral cut, and alternate daily tapping results in a higher d.r.c. than daily tapping. Higher d.r.c. is also observed for latex obtained from high-panel tapping compared with that from low-panel tapping. Furthermore, intensive tapping or drastic tapping causes marked decrease in d.r.c.

The high d.r.c. occurring at the end of a dry season is an effect of seasonal variation. Although an inverse relationship between productivity and d.r.c. is generally found for any one tree, no such correlation has been reported for different clones[6,9]. Lower d.r.c. is often found to result from application of yield stimulants to the tree, although d.r.c. generally increases again after some time[7,10].

In view of these variables, all the latices studied were collected from trees grown in one area, tapped on the same tapping system and without yield stimulation. Samplings were also made at intervals over a period of a year to include any variation due to seasonal changes. The dry rubber contents of six *Class I*, twenty-three *Class II* and fourteen *Class IIIA* clones were determined. By classifying the average d.r.c. values into ranges[1], the results shown in *Table 2* were obtained.

It can be seen that while most of the clones have average to above average d.r.c. (34%–41%), ten clones yield latices with high d.r.c. (more than 41%). Only two clones, RRIM 710 and PB 274, both of *Class IIIA*, give below average d.r.c. (31%–34%). None of the clones examined produce latices with d.r.c. lower than 25%, below which the latex is unsuitable for latex concentrate production due to decreased efficiency in the latex concentration process.

Acetone extract of total solids film. Unlike the d.r.c., this property has not been extensively studied. However, it has been shown[7] to increase after yield stimulation using 2,4,5-trichlorophenoxy acetic acid (2,4,5-T), and to decrease with the age of the tree. Generally, acetone extract varies between 3% and 6% in films from field latex and 2% and 5% in dry rubber.

Table 3 gives mean values for the forty-three clonal latices. These fall in a range between 3.25% and 6.11%, with PM 10 having the lowest content and PB 274 having the highest. Acetone extract consists of non-rubbers, some of which, particularly the lipids[11,12], are responsible for the stability of the rubber particles. This has probably contributed to the good stability of the concentrate of PB 274, but the low content of lipids of PM 10 does not give rise to an unstable concentrate (see later). The reason for this rests on the fact that many other factors besides lipids also exert influence on the stability of latex and its concentrate.

Nitrogen content. The nitrogen content of field latex is largely associated with the proteinaceous materials present. It has been reported[13] that about 30% of these materials are present in the rubber hydrocarbon phase and about 70% in the non-rubber phase. Most of these have been shown[6,14] to play an important role in the stability of *Hevea* latex. Certain influence of seasonal changes on this parameter had also been observed by Resing[6] in his study of some of the older clones. A range of 0.53%–0.80% (on total solids film) was reported for some latices[1,6,7]. Results from the present study indicate a very similar nitrogen content, varying from 0.51% to 0.87% *(Table 3)*.

Phosphorus and magnesium. Approximately one-third of the phosphorus in latex is found in the rubber hydrocarbon phase and the rest in the non-rubber phase[15]. Magnesium, on the other hand, is found mainly in the non-rubber fractions (C- and B-sera)[16]. Both phosphorus and magnesium have been shown to affect latex stability. While phosphorus compounds exert a stabilising effect, magnesium, in the form of divalent cation, is destabilising[17,18]. It has been shown that although the ratio of phosphorus/magnesium is correlated with the stability of

TABLE 3. ACETONE EXTRACT, NITROGEN, PHOSPHORUS AND MAGNESIUM CONTENTS OF FIELD LATEX OF FORTY-THREE CLONES PLANTED IN THE RRIM EXPERIMENT STATION (TOTAL SOLIDS FILMS)

Clone	Acetone extract (%) Mean	s.d.	Nitrogen content (%) Mean	s.d.	Phosphorus content (%) Mean	s.d.	Magnesium content (%) Mean	s.d.
Class I								
GT 1	4.18	0.27	0.80	0.06	0.19	0.04	0.09	0.01
RRIM 600	3.92	0.61	0.74	0.05	0.23	0.04	0.16	0.03
RRIM 712	3.40	0.77	0.71	0.02	0.22	0.02	0.15	0.05
PR 255	4.06	0.94	0.61	0.05	0.13	0.03	0.04	0.01
PR 261	3.74	0.66	0.64	0.08	0.22	0.05	0.13	0.02
PB 217	5.81	0.13	0.57	0.09	0.17	0.06	0.07	0.03
Class II								
RRIM 623	3.41	0.23	0.60	0.08	0.23	0.07	0.06	0.01
RRIM 628	4.33	0.26	0.64	0.04	0.22	0.04	0.07	0.02
RRIM 701	5.38	0.56	0.56	0.03	0.18	0.01	0.08	0.01
RRIM 703	3.49	0.57	0.69	0.07	0.30	0.03	0.10	0.01
RRIM 725	5.84	0.52	0.87	0.04	0.27	0.11	0.11	0.07
RRIM 728	3.68	1.06	0.73	0.06	0.22	0.03	0.16	0.02
RRIM 729	5.59	0.39	0.64	0.08	0.17	0.02	0.08	0.02
RRIM 805	3.89	0.50	0.64	0.09	0.21	0.05	0.10	0.02
RRIM 901	5.25	0.35	0.68	0.03	0.24	0.03	0.08	0.01
RRIM 905	4.99	0.72	0.68	0.05	0.26	0.06	0.12	0.03
PB 28/59	5.36	0.43	0.61	0.04	0.20	0.07	0.08	0.05
PB 230	3.86	0.52	0.73	0.06	0.24	0.09	0.16	0.08
PB 235	4.96	0.74	0.53	0.05	0.22	0.02	0.06	0.02
PB 254	4.21	0.18	0.68	0.10	0.24	0.05	0.09	0.02
PB 255	4.16	0.55	0.53	0.03	0.21	0.03	0.07	0.01
PB 260	4.40	0.37	0.53	0.03	0.19	0.02	0.06	0.02
PB 280	3.67	0.19	0.66	0.02	0.16	0.03	0.10	0.03
RRIC 100	3.66	0.80	0.70	0.07	0.16	0.04	0.09	0.02
RRIC 110	3.65	0.45	0.62	0.08	0.12	0.01	0.07	0.04
IAN 873	4.04	0.60	0.84	0.07	0.29	0.06	0.12	0.04
PM 10	3.25	0.86	0.62	0.07	0.22	0.04	0.14	0.03
BPM 24	4.22	0.43	0.73	0.05	0.17	0.03	0.11	0.02
Nab 17	3.91	0.37	0.69	0.04	0.27	0.02	0.07	0.02
Class IIIA								
RRIM 709	3.84	0.61	0.68	0.11	0.17	0.03	0.07	0.03
RRIM 710	4.06	0.52	0.85	0.05	0.28	0.06	0.11	0.04
RRIM 717	3.67	0.39	0.64	0.03	0.20	0.03	0.14	0.02
RRIM 730	3.64	0.15	0.51	0.05	0.13	0.01	0.05	0.02
RRIM 803	3.38	0.45	0.67	0.04	0.22	0.03	0.11	0.01
RRIM 804	4.02	0.42	0.78	0.05	0.22	0.03	0.09	0.02
RRIM 806	3.94	0.50	0.76	0.06	0.21	0.06	0.06	0.02
RRIM 809	3.83	0.16	0.52	0.14	0.21	0.05	0.07	0.01
PB 242	3.94	0.55	0.68	0.05	0.21	0.05	0.09	0.04
PB 274	6.11	1.40	0.85	0.07	0.33	0.03	0.12	0.06
PB 312	3.87	0.69	0.76	0.14	0.27	0.07	0.15	0.04
PM 8	3.65	0.46	0.74	0.07	0.25	0.05	0.14	0.04
RRIC 101	3.46	0.28	0.58	0.22	0.19	0.04	0.12	0.02
RRIC 102	3.64	0.62	0.68	0.06	0.18	0.03	0.06	0.01
L.S.D.		0.93		0.12		0.07		0.05
S.D.		0.58		0.07		0.05		0.03

L.S.D. — Least significant difference at 5% probability level
s.d. — Standard deviation, S.D. — overall s.d.

latex to a certain extent, it is by no means the only influencing factor[15]. Nevertheless, in the processing of latex concentrate, diammonium hydrogen phosphate is sometimes added to precipitate the undesirable free magnesium ions to ensure better stability of the concentrate produced.

Analyses of latices from the various clones revealed a phosphorus concentration ranging from 0.12% to 0.33% *(Table 3)*. Lower concentrations were detected in the case of magnesium, which varied from 0.04% to 0.16%. These levels are consistent with those reported earlier for some selected clones[7,14,19], although a lower phosphorus content of 0.08% and a lower magnesium content of 0.03% were reported for a very old clone of AVROS 50[7].

Copper and manganese. These two elements are known to be present in latex in relatively low concentration compared to other metals, such as potassium, magnesium, calcium and sodium. A range of 1–7 p.p.m. of copper and a concentration of less than 2 p.p.m. of manganese were detected in the clonal latices analysed.

Both copper and manganese ions are known to enhance oxidation of the rubber polymer[20,21], copper ion being the more potent one. It is believed that these two metals are present in latex in an inert form which could be activated to catalyse the degradation process during storage of rubber. So far, all the observations reported[20,21] concerned only the effect of copper and manganese ions added to the latex system. No study has yet been carried out on the action of the naturally occurring copper and manganese. Such a study could be interesting and informative.

Latex Concentrate Properties

The latex concentrates studied were those of the centrifuged type preserved with high ammonia. This is the predominant latex type produced in Malaysia. Of the important properties required by the specifications as stated in *ISO 2004*, the mechanical stability time, the KOH number and copper and manganese contents are of interest in view of their sensitivity to clonal variation[6,7,15,17].

KOH and VFA numbers. The KOH number is a measure of the content of anions in latex. These include those of the volatile fatty acids, higher fatty acids, phosphates, carbonates and bicarbonates. The volatile fatty acids are the products of bacterial action on latex due to inadequate preservation, and are normally measured separately by the VFA number, which is the number of grammes of potassium hydroxide equivalent to the volatile fatty acid contained in 100 g of total solids. The presence of carbonates and bicarbonates may be due to the absorption of carbon dioxide during exposure of the latex to air. The other anions are inherent components of the latex system, the contents of which may vary from clone to clone. The KOH number is therefore defined as the number of grammes of potassium hydroxide equivalent to the acid radicals combined with ammonia containing 100 g of total solids. A high KOH number and a high VFA number indicate inadequate preservation of latex.

Measurement of the KOH number showed that clonal variation in this property was not marked as indicated by the somewhat small range of 0.56–0.75 *(Table 4)*. Even less variation was observed in the case of the VFA

TABLE 4. POTASSIUM HYDROXIDE, VOLATILE FATTY ACID NUMBERS AND CONTENTS OF COPPER AND MANGANESE FOR LATEX CONCENTRATES FROM FORTY-THREE CLONES

Property	Range	ISO 2004 specification
KOH No.	0.56 — 0.75	Not to exceed 1.0
VFA No.	Less than 0.04	Not to exceed 0.2
Copper	Less than 3 p.p.m.	Maximum 8 p.p.m.
Manganese	Less than 1 p.p.m.	Maximum 8 p.p.m.

All KOH and VFA values were obtained from samples after three months' storage numbers which remained very low for all the clones, showing that preservation of all the concentrates examined had been adequate. In view of these very low VFA numbers, it can be concluded that the KOH number reflects the concentrations of long-chain carboxylates and inorganic anions in the various clonal latex concentrates. Magnitudes of both KOH and VFA numbers are well within the latex concentration specifications *(Table 4)*.

Mechanical stability time (MST). This is a measure of the colloidal stability of latex concentrate. It is assessed by a measure of the resistance of the latex particles to irreversible flocculation or coagulation when subjected to mechanical stirring. The MST of a freshly prepared latex concentrate is always low. During storage at ambient temperature, it increases very rapidly for three to four weeks, after which the rise becomes more gradual for the next one to two months. The initial rapid increase in MST has been correlated to the increasing content of higher fatty acid soaps with time, arising from the hydrolysis of some lipids (mainly phospholipids and glycolipids) on the surface of the rubber particles[22]. As most of these soaps are absorbed on the surface of the latex particles, this gives rise to higher surface electrical charge density, greater particle repulsion forces, and hence higher MST. The subsequent slow rise in MST is due to exposure of latex to oxygen in air[23]. According to the specification limit, a minimum MST of 650 s is required below which the latex is considered unstable.

Mechanical stabilities of all the clonal concentrates studied are shown in *Table 5* which refers to values after three months' storage. Generally, most of the clones are capable of producing good stabilities although soap treatment has to be used in some cases for improved MST.

It was observed that the following clonal latex concentrates exhibited low latex stabilities (MST < 650 s) even after three months' storage:

Class I : RRIM 600, RRIM 712, PR 255, PR 261 and PB 217

Class II : RRIM 703, RRIM 729, RRIM 905, PB 254, RRIC 100 and RRIC 110

Class IIIA : RRIM 717, RRIM 803, RRIM 804, RRIM 806, RRIM 809, PB 242 and PM 8

Various factors which are associated with the inherent properties of the latex system could be responsible for the low latex stabilities of these clones. These factors include the lower concentration of higher fatty acid soaps, lower contents of proteins and saponifiable lipids on the rubber particle surface, and excessive quantity of inorganic cations in the serum phase. In order to identify the influence of the individual factors on the instabilities of the above clonal latices, a separate and systematic study is required.

Parentage of clones also appears to play a role in latex stability in view of the following observations. One of the parents of each of the three low-stability *Class I* clones — PR 255, PR 261 and RRIM 712 — had been found to yield unstable latex concentrates. They are PR 107 for clones PR 255 and PR 261 and RRIM 605 for clone RRIM 712 *(Table 1)*. Similarly, RRIM 703 of *Class II* and RRIM 806 and RRIM 809 of *Class IIIA* have the unstable RRIM 600 as one of their parents. Parentage is obviously not the only influencing factor since the RRIM 600 clone which gives unstable latex concentrates, has parents (Tjir 1 and PB 86) which both show high concentrate stabilities. This is also the case with the unstable RRIM 803 clone of *Class IIIA*, whose parents, RRIM 501 and RRIM 623, are known to produce latex concentrates of high MST. Possible influence of parentage on the other low stability clones (with the exception of PM 8 which is a primary clone) would not be discussed due to insufficient information on the MST values of their parent clones, many of which are either very old clones or are garden materials grown only for breeding purposes.

Anionic long-chain fatty acid soaps, when added to latex concentrates, are known to

TABLE 5. MECHANICAL STABILITY TIME OF LATEX CONCENTRATES FROM DIFFERENT CLONES AFTER THREE MONTHS' STORAGE

Class	MST (s)			
	< 650	650-900	900-1200	> 1200
I	PR 255[a] PB 217	GT 1 RRIM 712[a] PR 261[a]	RRIM 600[a]	—
II	RRIM 703[a] RRIM 729[a] RRIM 905[a] RRIC 100[a]	RRIM 728 RRIM 805 PB 254[a] PB 280 IAN 873 BPM 24	RRIM 623 RRIM 628 RRIM 901 PM 10 PB 255	RRIM 701 RRIM 725 PB 28/59 PB 230 PB 235 PB 260 RRIC 110[a] NAB 17
IIIA	RRIM 804[a] RRIM 806[a]	RRIM 710 RRIM 803[a] PB 242[a] PB 312 RRIC 102	RRIM 709	RRIM 717[a] RRIM 730 RRIM 809[a] PB 274 PM 8[a] RRIC 101

[a]Latices treated with 0.02% ammonium laurate

increase their mechanical stabilities[6,24]. This is mainly due to the adsorption of the surface-active soap molecules on the rubber particle surface. It is interesting to note that when 0.02% ammonium laurate (on latex weight) was added to the above-mentioned low-stability concentrates, different responses were obtained. While some clonal latices showed a marked increase in MST, others gave a smaller change, as illustrated in *Figure 1.* Of the seventeen clonal latices tested after three months' storage, ten responded well, elevating their MST from below 650 s to above this specification limit. The other seven clones also indicated some response, but their MST remained below 650 s under the experimental conditions. The exact causes for this behaviour are not yet fully understood, but it is likely that the nature and composition of the protein and lipid components on the rubber particle surface are implicated. Latices from these latter clones are obviously not suitable for latex concentrate production, unless perhaps higher soap concentrations can be used to improve their stabilities further.

Latices of low stabilities are often associated with high KOH numbers which usually have high VFA numbers (due to inadequate preservation of latex). In the present study, a relationship between MST and KOH has not been obtained, as shown by the statistical analysis of data from the forty-three clones which indicated that the correlation between these two parameters was insignificant: MST = -1520 KOH + 1806 ($r = -0.19$). This lack of correlation could probably be partly explained firstly, by the fact that not all the acidic anions as measured by the KOH number exert destabilising effects on latex particles. Those of the higher fatty acids, for example, when adsorbed onto the rubber surface, can in fact confer latex stability. Secondly, as reported by Yip and Subramaniam[15] and also briefly mentioned earlier, the MST is greatly influenced by a number of other inherent latex properties which show variability between clones.

Copper and manganese. As expected, the levels of these two elements in latex concentrates are lower than those in field latex. About

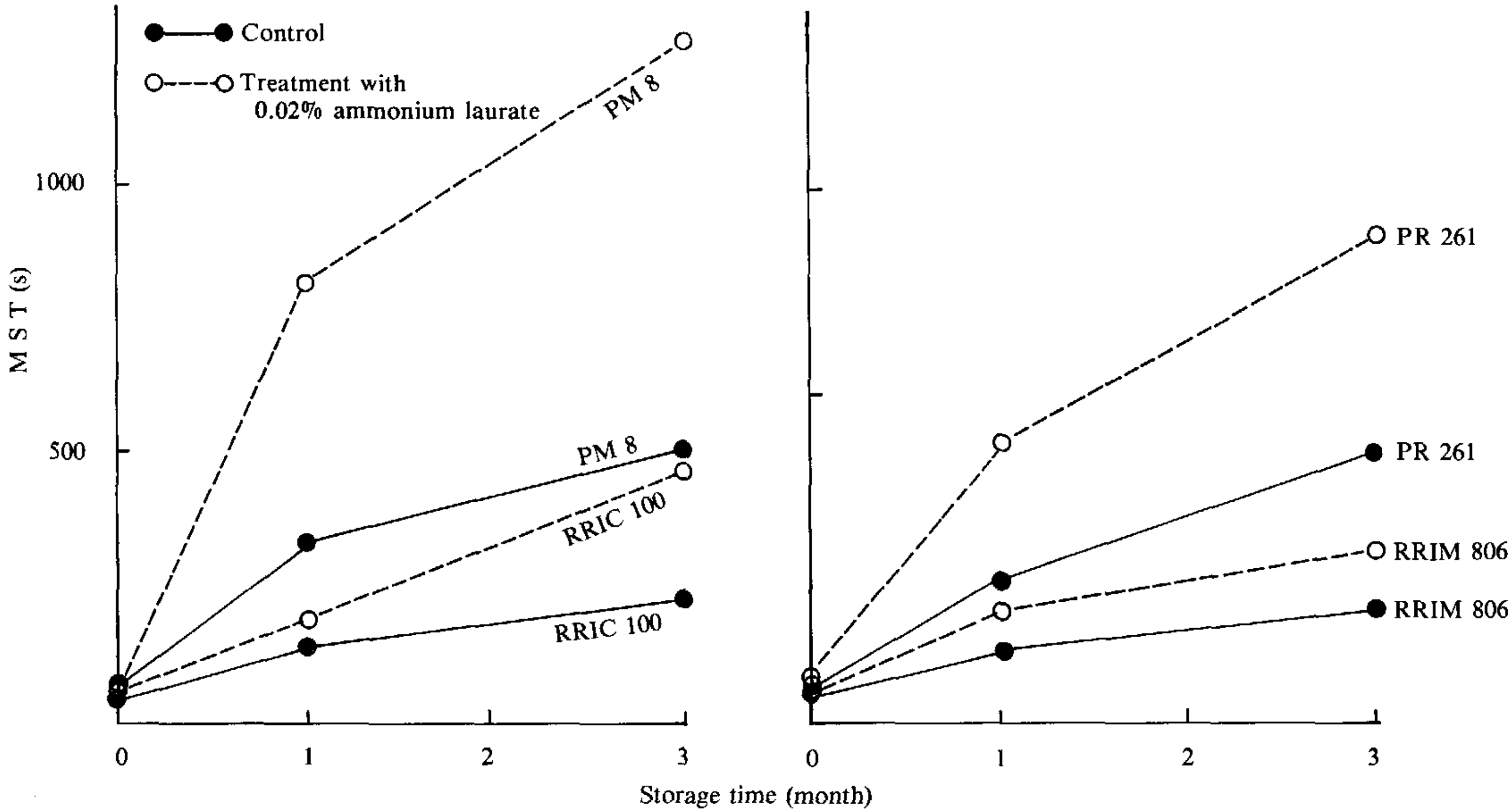

Figure 1. Effect of 0.02% ammonium laurate on the mechanical stability of different clonal latex concentrates in the form of HA latices.

3 p.p.m. or less of copper and 1 p.p.m. or less of manganese were detected in the concentrates from the various clones *(Table 4)* as compared to 1–7 p.p.m. of copper and about 2 p.p.m. of manganese in their corresponding field latices. The difference is probably due to the partial removal of some of the non-rubber substances during the centrifugation process.

Bulk Rubber Properties

The dry rubbers tested in this study were those of the Standard Malaysian Rubber — whole field latex (SMR WF) and the constant-viscosity (SMR CV) grades, and the properties examined are those included in the specifications for SMR production[25]. As all the rubbers were prepared using the same processing procedure, any variation detected in the properties studied could be considered as mainly due to differences between clones, except for dirt and volatile matter contents which are actually influenced by the processing of rubber.

Mooney viscosity. This parameter is universally used in all the rubber consumer countries. It gives an indication of the amount of mechanical work required on the raw rubber to give mixes with consistent rheological properties after standard plastication, compounding and mixing. This means that a rubber with very high Mooney viscosity, for example, may require long premastication times or need expensive peptisers to obtain a product of a workable and consistent viscosity, whereas the soft rubbers with low Mooney viscosities require no prior mastication.

Mooney viscosity of rubber sometimes changes during storage. This is due to the fact that natural rubber often hardens, resulting in higher bulk viscosity, when it is stored at ambient temperature and humidity over a period of time. This hardening process is accelerated at elevated temperatures and dry conditions. It has been postulated to be mainly due to the crosslinking reaction between the rubber molecules involving the aldehyde or carbonyl groups[26,28,29] and certain aldehyde condensing groups in the non-rubber phase including some amino acids[30,31]. Addition of a monofunctional carbonyl reagent, such as hydroxylamine, to latex before coagulation inhibits this reaction, *via* the deactivation of the carbonyl group hence rendering the rubber less prone to hardening[32,33]. Such is the case of the CV rubbers. It may therefore be mentioned that Mooney viscosities of the CV rubbers may be regarded as having values closer to the true values as produced by the trees.

Although in the SMR Scheme, Mooney viscosity is not specified for any of the non-viscosity-stabilised grades, this property is very important in the case of the viscosity-stabilised (or CV) rubbers, which require different viscosity ranges for different CV grades[2,5], e.g. the most demanded CV grade of SMR CV 60 requires a range of 55–65 Mooney units.

Table 6 shows the results obtained for CV rubbers from *Class I*, *Class II* and *Class IIIA* clones. The average Mooney viscosity is 55–83 units for the six *Class I* clones, 39–89 units for the twenty-three *Class II* clones and 46–78 units for the fourteen *Class IIIA* clones. By classifying the viscosity values into five arbitrary ranges as illustrated in *Table 7*, it is apparent that although there are some clones producing rubbers with the preferred medium viscosity range, about one-half and more than one-half the number of the good yielding clones recommended in *Class I* and *Class II* respectively produce medium-hard to hard rubbers. There are indeed very few soft or medium-soft rubber clones. It may be mentioned that unless these softer rubber clones are also selected for planting, the production of SMR CV 60 grade from the harder rubber clones, using the usual practice of blending latices with high and low V_R to give the required viscosities, would encounter some difficulties in the future. This would particularly be so when the existing softer rubber clones such as the RRIM 501 becomes unavailable due to wind damage. Fortunately, three more low V_R clones are identified among the newer ones in *Class IIIA*. They are RRIM 804, RRIM 806 and PB 312. Although these are still experimental planting materials, they have the potential to be promoted to *Class II* if they continue to show good yield and growth performances and no secondary defects. CV 60 can nevertheless be

TABLE 6. RAW RUBBER PROPERTIES OF FORTY-THREE CLONES IN THE RRIM EXPERIMENT STATION

Clone	V_R (CV rubber) Mean	s.d.	P_o Mean	s.d.	PRI (%) Mean	s.d.	Ash (%) Mean	s.d.	Nitrogen (%) Mean	s.d.	Colour
Class I											
GT 1	58	2	45	3	90	6	0.38	0.03	0.56	0.03	
RRIM 600	*55*	*4*	*42*	*2*	*91*	*3*	*0.37*	*0.02*	*0.50*	*0.02*	L
RRIM 712	59	4	45	3	93	6	0.44	0.04	0.48	0.02	L
PR 255	69	5	48	3	83	5	0.30	0.05	0.48	0.03	
PR 261	73	4	53	2	92	5	0.35	0.09	0.47	0.03	L*
PB 217	83	5	59	3	80	8	0.21	0.02	0.41	0.06	
Class II											
RRIM 623	63	4	49	5	92	4	0.37	0.02	0.43	0.01	
RRIM 628	84	8	57	6	85	6	0.38	0.09	0.43	0.01	
RRIM 701	55	3	39	3	99	8	0.43	0.06	0.44	0.04	
RRIM 703	56	8	42	7	94	7	0.41	0.06	0.49	0.04	
RRIM 725	72	8	49	5	83	3	0.42	0.03	0.50	0.04	
RRIM 728	39	3	31	3	105	8	0.38	0.09	0.52	0.04	L
RRIM 729	66	6	47	4	90	2	0.34	0.04	0.48	0.02	
RRIM 805	55	4	40	4	93	7	0.28	0.08	0.49	0.02	
RRIM 901	61	3	46	4	89	3	0.41	0.04	0.46	0.01	L*
RRIM 905	65	4	48	4	91	3	0.38	0.01	0.45	0.02	L*
PB 28/59	87	6	58	3	85	3	0.36	0.05	0.40	0.03	
PB 230	64	4	48	4	89	5	0.39	0.04	0.45	0.03	
PB 235	76	7	55	3	85	7	0.37	0.06	0.38	0.02	L*
PB 254	83	4	59	3	84	4	0.32	0.03	0.44	0.03	L*
PB 255	72	6	55	3	89	8	0.38	0.04	0.39	0.01	
PB 260	63	7	48	3	91	8	0.36	0.04	0.38	0.02	L
PB 280	87	6	61	5	82	2	0.35	0.05	0.42	0.03	
RRIC 100	69	8	46	6	87	6	0.30	0.04	0.52	0.05	
RRIC 110	67	5	49	2	91	5	0.28	0.08	0.46	0.01	L*
IAN 873	89	5	60	4	85	4	0.28	0.02	0.50	0.04	L*
PM 10	86	7	59	5	84	5	0.29	0.10	0.43	0.04	L*
BPM 24	50	3	39	3	97	8	0.41	0.08	0.48	0.06	
Nab 17	72	5	51	3	89	5	0.37	0.06	0.47	0.02	
Class IIIA											
RRIM 709	69	4	49	3	83	5	0.37	0.09	0.47	0.04	L
RRIM 710	58	2	43	4	96	6	0.33	0.04	0.54	0.04	L
RRIM 717	47	2	36	4	105	9	0.49	0.08	0.44	0.04	L*
RRIM 730	67	3	51	4	87	4	0.31	0.05	0.39	0.02	L*
RRIM 803	60	5	46	4	103	6	0.41	0.07	0.47	0.02	L
RRIM 804	53	4	40	4	103	4	0.34	0.04	0.57	0.03	L
RRIM 806	46	2	34	2	91	8	0.24	0.06	0.52	0.03	L*
RRIM 809	55	2	43	3	90	7	0.25	0.05	0.49	0.01	L*
PB 242	67	1	51	2	91	3	0.30	0.07	0.43	0.01	L
PB 274	72	3	56	2	91	4	0.31	0.04	0.51	0.06	L*
PB 312	52	2	37	3	88	9	0.27	0.08	0.54	0.07	L*
PM 8	57	3	44	6	90	10	0.31	0.03	0.49	0.03	
RRIC 101	77	8	53	5	90	6	0.30	0.08	0.47	0.03	L*
RRIC 102	78	3	53	3	88	4	0.22	0.03	0.48	0.03	L*
L.S.D.	8		6		9		0.09		0.05		
S.D.	5		4		6		0.06		0.03		

L.S.D. : Least significant difference
S.D. : Standard deviation
L : Colour less than six Lovibond units
L* : Colour less than six Lovibond units on treatment with sodium metabisulphite

TABLE 7. MOONEY VISCOSITY OF RAW RUBBERS FROM CLASS I, CLASS II AND CLASS IIIA CLONES

Raw rubber viscosity (CV)	V_R range [ML (1 + 4) min, 100°C]	Number of clones		
		Class I	Class II	Class IIIA
Low	< 45	nil	1	nil
Medium-low	45–55	nil	1	4(1)
Medium	55–65	3	8(2)	4(1)
Medium-hard	65–75	2	6(1)	4(2)
Hard	> 75	1	7(2)	2

Figures within brackets indicate the number of clones withdrawn from the recommendation, see *Table 1*.

produced with clonal latices which give medium rubber viscosities, and do not require blending with other latices. These clones are:

Class I : GT 1, RRIM 600 and RRIM 712

Class II : RRIM 623, RRIM 701, RRIM 703, RRIM 805, RRIM 901, RRIM 905, PB 230 and PB 260

Class IIIA : RRIM 710, RRIM 803, RRIM 809 and PM 8

It is also observed that while 70% of the RRIM clones studied (fourteen out of twenty) produced low to medium viscosity rubbers, 70% of the PB clones (seven out of ten clones) gave medium-hard to hard rubbers. The influence of genetic factors on rubber viscosity is complex but the following relationships may be worth noting. A closer examination of the PB clones reveals that, except for PB 28/59 which is a primary clone (V_R = 87 units), all the other harder PB clones have a common parent of either PB 5/51 (V_R = 91 units) or PB 28/59. This parentage effect perhaps is responsible for the high viscosity observed in these clones. It is however interesting to note that clones PB 230, PB 260, RRIM 901 and RRIM 905, which also have PB 5/51 as one of their parents, yielded rubbers of medium viscosities. In these cases, the influence of their other parents may be more prevailing. PB 312, the only PB clone that gives medium-soft rubber, on the other hand, does not have PB 5/51 nor PB 28/59 as one of its parents *(Table 1)*. Similarly, none of the RRIM clones has a PB parent, with the exception of RRIM 901, RRIM 905 and RRIM 600. It may be of interest to point out that RRIM 600 rubber has lower V_R (55 units) than those of both its parents, *i.e.* PB 86 (V_R = 76 units) and Tjir 1 (82 units)[27].

Wallace plasticity. Besides Mooney viscosity, the important property of bulk viscosity of rubber is also measured by Wallace plasticity using the Wallace plastimeter. Unlike Mooney viscosity, there is a specification limit for this parameter in the SMR production of non-viscosity-stabilised rubber grades[25]. A minimum of 30 units is required, below which the rubber is considered to be too soft.

The plasticity values determined for the same forty-three clones are shown in *Table 6*. A range varying from 42 to 59 units was indicated for the *Class I* clones, 31–61 units for the *Class II* clones and 34–56 units for the *Class IIIA* clones, all of which are above the limit specified.

Correlation between Mooney viscosity and Wallace plasticity. These two parameters are known to be related. Their relationship however is dependent on the history of the rubber samples involved since differences in processing, drying conditions and mastication could affect it. The somewhat different relationships reported for total solids rubbers, viscosity-stabilised and non-stabilised crepes, and masticated rubbers[26,34–37] are a case in point.

Statistical analyses of the present data obtained from crumb rubbers of forty-three clones (with no mastication) showed the following correlations between the two parameters. For non-viscosity-stabilised SMR WF type rubbers:

$V_R = 1.33\ P_o + 7.93$ where the coefficient of correlation $r = 0.93$

For the viscosity stabilised SMR CV type rubbers:

$V_R = 1.38\ P_o + 7.01$ where $r = 0.95$

The coefficient '*r*' in both cases is significant at $P < 0.001\%$. The relationships are also expressed graphically as shown in *Figure 2*. The slightly higher gradient of the straight-line relationship for CV rubbers compared to that for the non-CV rubbers is consistent with that observed by Subramaniam[26] who, in his study of crepe rubbers, attributed this to the presence of different gel contents which could give rise to varying increases in the P_o and V_R values.

Comparison of the V_R values obtained from the above equations with those estimated from equations reported for crepe rubbers[26] indicated a difference of 1.8% to 7.6% when the P_o value of non-CV rubbers varied from 30 to 60 units. A smaller difference of 0.002% to 6.2% was observed in the case of the CV rubbers for the same P_o range.

Correlation between Mooney viscosity and storage hardening. The hardening phenomenon of natural rubber is usually assessed by the 'accelerated storage hardening' test in which the rubber is stored at 60°C over phosphorus pentoxide in vacuum for 48 h, and the degree of storage hardening is expressed in terms of the resulting increase in Mooney viscosity, ΔV_R, or the increase in the Wallace plasticity number, ΔP.

In the present investigation, the influence of the initial bulk viscosity (V_R) on the degree of storage hardening (ΔV_R) was examined. V_R as measured, is the difference between the viscosity after storage hardening (V_{SH}) and the initial bulk viscosity of the non-viscosity-stabilised rubber before the test, *i.e.*

$$\Delta V_R = V_{SH} - V_R$$

Analyses of the data of the forty-three clones gave the following correlation (*Figure 3*) between ΔV_R and V_R:

$$\Delta V_R = -0.85\ V_R + 101.88$$
$$r = -0.81\ (P<0.001\%)$$

Since V_R of non-CV rubbers tends to increase somewhat during or after their preparation, due to the presence of the aldehyde groups, a more accurate way to present the value of ΔV_R would perhaps be

$$\Delta V_R^1 = V_{SH} - V_{R(CV)}$$

where ΔV_R^1 denotes the intrinsic extent of storage hardening of the rubber sample, the initial viscosity of which is not affected by any crosslinking reaction prior to the test, and can thus be represented by V_R of the corresponding viscosity-stabilised sample, $V_{R(CV)}$. This gives a relation with a better correlation coefficient (*Figure 4*), expressed by the following equation:

$$\Delta V_R^1 = -0.89\ V_{R(CV)} + 105.86$$
$$r = -0.86\ (P<0.001\%)$$

Clonal rubbers with lower initial bulk viscosities are associated with greater extents of storage hardening and *vice versa*. This is in agreement with the higher aldehyde group concentration generally found in the softer clonal rubbers, compared to the harder clonal rubbers[26].

The initial bulk viscosity is also correlated to the storage hardening index (SHI) which is defined as:

$$\text{SHI} = \frac{\text{Viscosity after storage hardening}}{\text{Original viscosity}}$$

Figure 5 shows the relationship which is also represented by

$$\text{SHI} = -0.024\ V_R + 3.40$$

where $r = -0.88\ (P<0.001\%)$

This is somewhat different from that reported for crepe rubbers[26] where

$$\text{SHI} = -0.017\ V_R + 2.8.$$

V_2 values in both cases are those of the CV rubbers. The difference is again likely to be related to the history of the samples.

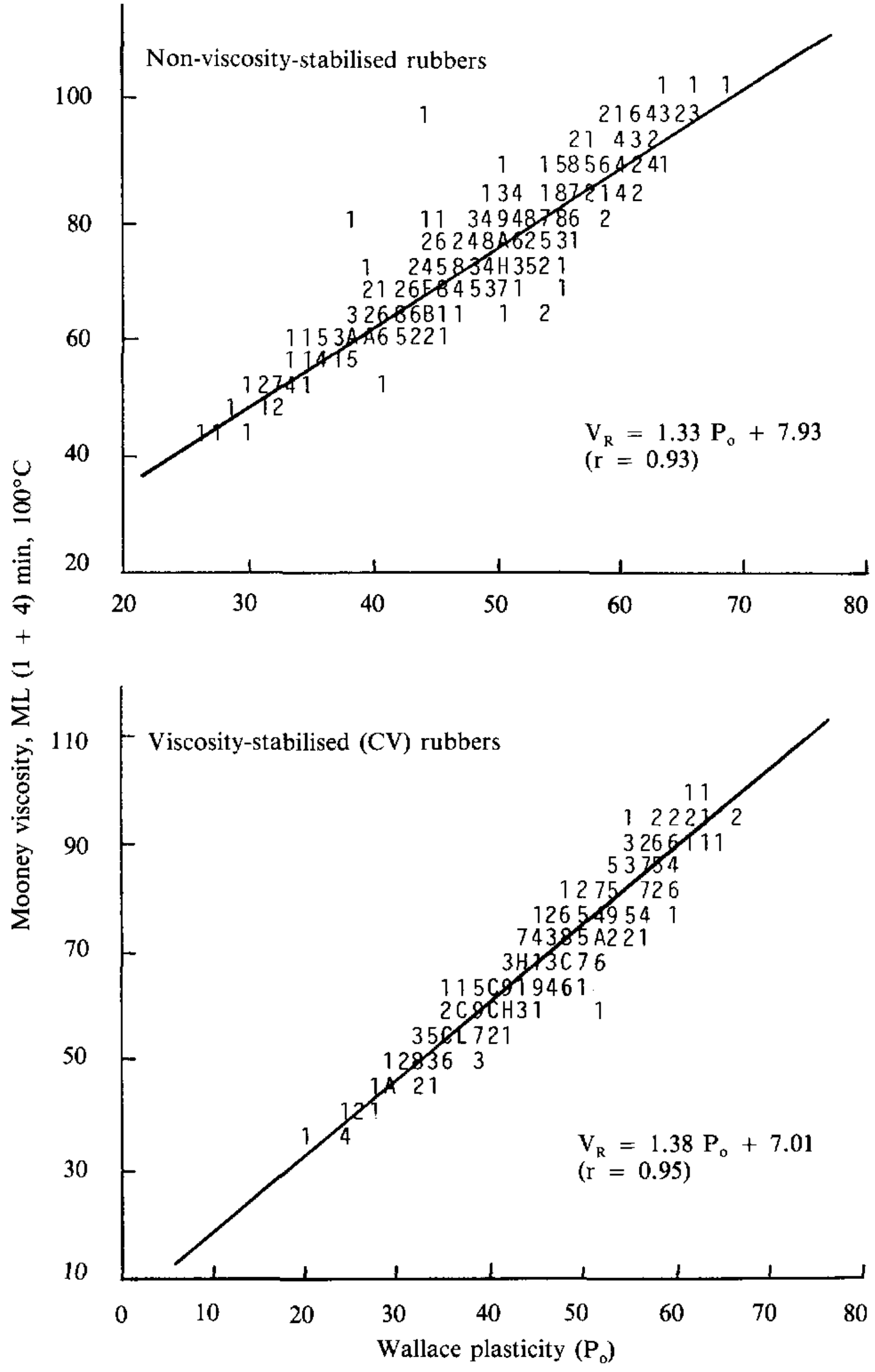

Figure 2. A plot of Mooney viscosity against Wallace Plasticity of raw rubbers from forty-three clones. The numbers 1–9 stated in the graph denote the number of points plotted in a given position. Similarly the alphabets A, B, C .... L represent 10, 11, 12 .... 16 points respectively.

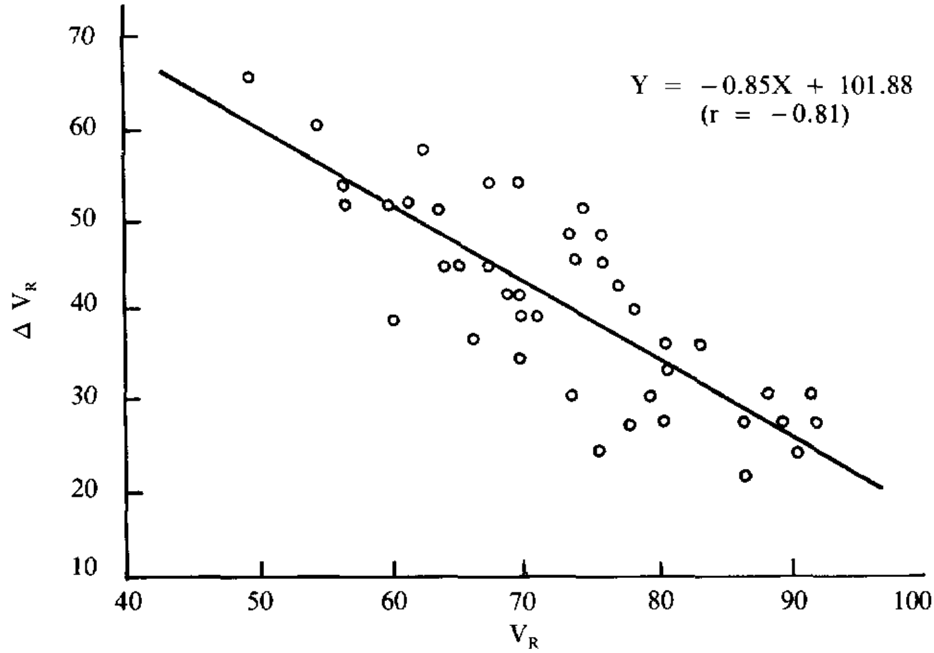

Figure 3. Correlation between the extent of storage hardening, ΔV_R, and the initial bulk viscosity of clonal rubbers.

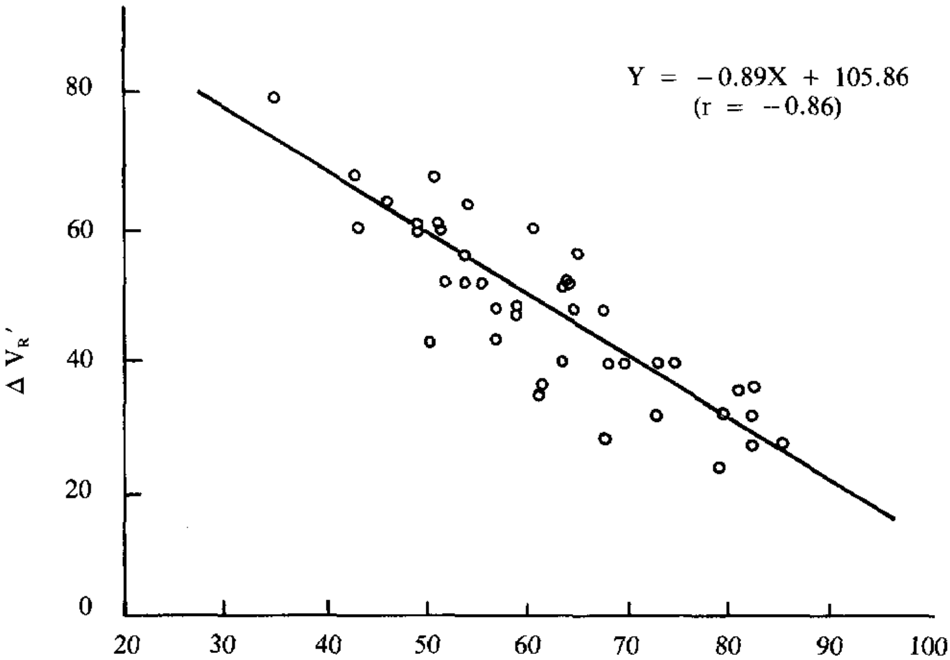

Figure 4. Correlation between the intrinsic extent of storage hardening, $\Delta V_R'$ and the original bulk viscosity, $V_{R(CV)}$, for the same clonal rubbers as in Figure 3.

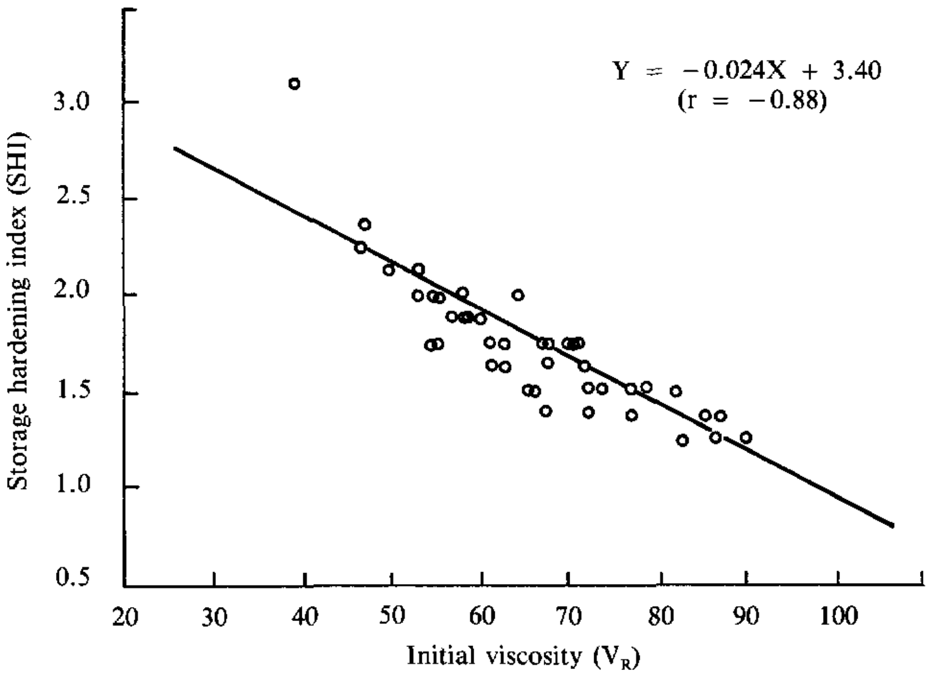

Figure 5. Relationship between initial bulk viscosity, $V_{R(CV)}$, and the storage hardening index (SHI) for forty-three clonal rubbers.

Plasticity retention index. This is a measure of the resistance of rubber to molecular breakdown by heat. It is assessed by the percentage change of the original plasticity when the rubber is heated at 140°C for 30 min, *i.e.*

$$\text{PRI } (\%) = \frac{P_{30}}{P_o} \times 100$$

where P_o is the original plasticity

P_{30} is the aged plasticity

High values correspond to good heat resistance. PRI determinations of the forty-three clonal rubbers indicated a value ranging from 81% to 105% *(Table 6),* all of which are within the SMR specification which requires a minimum of 60% for all latex grades[25].

As P_o values exhibit clonal differences, they are expected to induce certain variation in the plasticity retention index measurements. The following equations were obtained for the clonal rubbers:

Non-CV rubbers, PRI $= -0.52\, P_o + 115.23$

($r = -0.46$, significant at 0.001%)

CV rubbers, PRI $= -0.09\, P_o + 88.59$

($r = -0.16$, significant at 0.01%)

That rubbers with lower plasticity have higher PRI and those with higher plasticity tend to have lower PRI is suggested in the case of the non-CV rubbers in spite of the somewhat low '*r*' value. Three reactions are known to occur during the PRI test: degradation; some crosslinking by free radicals; and, a certain amount of hardening due to the aldehyde groups and the aldehyde-condensing groups. The correlation between the two parameters for the non-CV rubbers is mainly attributed to the hardening reaction since such correlation is very much reduced or absent[26] in the case of the viscosity-stabilised (CV) rubbers.

Ash and nitrogen contents. The ash content represents the amount of mineral matter present in the rubber, such as carbonates and phosphates of potassium, magnesium, calcium, sodium and other trace elements. A high ash content in rubber could result from contamination during latex collection or processing. The nitrogen content of dry rubber, on the other hand, indicates the quantity of proteins present. Among them, certain proteinacous materials had been shown to exert various effects on the technological properties of rubber[38–41].

The SMR specification limits for these two characteristics are a maximum of 0.50% for ash and a maximum of 0.60% for nitrogen. *Table 6* shows the results obtained from the present investigation, indicating that all the forty-three clonal rubbers have ash contents varying from 0.21% to 0.49%, and nitrogen level ranging from 0.38% to 0.58%. These clonal rubbers should all meet the specification requirements if they are not contaminated during processing.

Colour. This is an essential property in the production of light-coloured rubbers, such as the SMR L grade which requires a colour limit of six units or less on the Lovibond colour scale[25].

The discolouration of raw rubber is usually due to the polyphenol oxidases in latex reacting with the naturally occurring phenolic substances in the presence of atmospheric oxygen, forming certain coloured products. It is sometimes due to the presence of non-rubber particles which are coloured, particularly the brightly coloured carotenoid Frey-Wyssling bodies. The browning of rubber which occurs in some cases, is often associated with the naturally occurring amines in the presence of divalent metal ions[6]. It therefore appears that all the known causative factors for the discolouration of rubber involve the non-rubber components of the latex system, the composition of which varies from clone to clone, and to a certain extent also, from day to day[6,14]. It is thus not surprising that such changes could induce variability in the colour of the derived rubber. Furthermore, this property could also be affected by differences adopted in the processing conditions of rubber, such as the preservation and dilution of latex, the coagulation method, the maturation and drying temperature.

Under the conditions employed in the present study, in which all the rubber samples were subjected to a single set of processing conditions, nine clones were found to yield rubbers with a consistently light colour (< 6 Lovibond units). A further sixteen clones produced rubbers which satisfied the colour requirement when the latex was treated before coagulation with 0.04 p.h.r. sodium meta-bisulphite — a compound normally added to latex to inhibit the enzymic darkening *(Table 6)*. In these latter cases, a dominant role by the oxidases is implied. As the above-mentioned non-rubber components involved in the discolouration process have not been investigated in this study, it is not possible to identify the extent of their influence on the colour of the various clonal rubbers. Such a study should be informative.

Curing characteristics. Although not a specified property, consistency in cure behaviour is important in determining the ease with which a product can be fabricated. In the SMR Scheme, the cure test used to measure cure differences between samples has been, since 1970, the MOD Cure Indicator system[5,42]. This measures the relaxed modulus at 100% extension (MR 100) of the rubber sample, vulcanised at 140°C for 40 min using the ACS 1 mix, giving a single point value which is used to characterise both the rate and state of cure. The measurements are classified as

MOD 5 (slow)	:	0.45–0.55 MPa
MOD 6 (moderate)	:	0.55–0.65 MPa
MOD 7 (fast)	:	0.65–0.75 MPa

Table 8 gives MR100 values of all the forty-three clones tested. It can be seen that while the non-viscosity-stabilised rubbers showed MR100 values varying between 0.53 MPa and 0.70 MPa, the CV-rubbers indicated a narrower range of 0.53 MPa to 0.63 MPa.

In recent years, a rheometric test has been preferred to characterise cure behaviour[42,43]. This test furnishes a rheograph in which the cure behaviour can be comprehensively defined

TABLE 8. CURE CHARACTERISTICS OF FORTY-THREE CLONAL RUBBERS — MR 100 (40 MIN/140°C) AND RHEOMETRIC (160°C) MEASUREMENTS USING ACS 1 MIX

Clone	Non-CV Rubber								CV Rubber							
	MR 100 (MPa)		Torque modulus ΔT (Nm)		Cure rate $(t_{90}-t_2)$ min		Scorch time t_2 (min)		MR 100 (MPa)		Torque modulus ΔT (Nm)		Cure rate $(t_{90}-t_2)$ min		Scorch time t_2 (min)	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Class I																
GT 1	0.64	0.03	3.819	0.305	8.3	0.8	1.5	0.2	0.58	0.04	3.571	0.362	9.0	1.2	1.8	0.2
RRIM 600	0.63	0.05	3.786	0.339	8.8	1.9	1.7	0.2	0.57	0.04	3.424	0.170	10.1	1.8	2.0	0.2
RRIM 712	0.65	0.05	3.899	0.294	8.1	1.6	1.5	0.2	0.58	0.02	3.469	0.158	9.7	1.3	1.8	0.2
PR 255	0.61	0.04	3.616	0.136	9.0	1.2	1.7	0.2	0.59	0.05	3.537	0.192	9.2	1.3	1.7	0.2
PR 261	0.65	0.05	3.808	0.305	7.8	1.1	1.6	0.2	0.59	0.02	3.447	0.113	8.9	1.0	1.8	0.2
PB 217	0.53	0.06	3.209	0.475	10.5	2.6	2.0	0.6	0.53	0.08	3.040	0.373	11.9	2.1	2.3	0.5
Class II																
RRIM 623	0.59	0.07	3.627	0.452	8.3	1.2	1.7	0.3	0.57	0.06	3.322	0.142	10.0	1.2	1.9	0.3
RRIM 628	0.57	0.03	3.424	0.226	8.7	0.9	1.8	0.2	0.55	0.03	3.322	0.316	10.5	0.9	1.9	0.3
RRIM 701	0.63	0.03	3.763	0.146	7.9	0.7	1.4	0.1	0.59	0.01	3.503	0.102	8.8	0.5	1.6	0.1
RRIM 703	0.65	0.03	3.865	0.113	7.8	1.0	1.6	0.2	0.59	0.01	3.503	0.170	9.1	1.1	1.8	0.1
RRIM 725	0.65	0.02	3.899	0.305	7.4	0.6	1.4	0.2	0.61	0.02	3.605	0.226	8.1	0.6	1.7	0.2
RRIM 728	0.70	0.04	4.328	0.315	7.0	1.3	1.5	0.2	0.58	0.02	3.548	0.136	9.2	1.0	1.9	0.3
RRIM 729	0.68	0.04	3.955	0.249	6.8	0.7	1.4	0.1	0.59	0.03	3.424	0.158	8.7	0.8	1.8	0.2
RRIM 805	0.62	0.08	3.774	0.497	8.3	2.2	1.5	0.4	0.61	0.07	3.627	0.463	8.4	2.2	1.7	0.5
RRIM 901	0.62	0.01	3.668	0.192	8.0	0.5	1.7	0.1	0.59	0.01	3.503	0.124	8.5	0.8	1.8	0.1
RRIM 905	0.59	0.03	3.616	0.339	8.0	1.6	1.7	0.3	0.61	0.07	3.345	0.090	9.2	1.1	1.9	0.2
PB 28/59	0.59	0.03	3.413	0.226	8.0	0.9	1.6	0.3	0.54	0.02	3.175	0.068	9.1	0.2	1.9	0.5
PB 230	0.61	0.05	3.808	0.350	8.2	1.0	1.5	0.2	0.57	0.05	3.571	0.407	9.1	0.7	1.9	0.3
PB 235	0.60	0.02	3.435	0.237	8.3	1.1	1.6	0.3	0.56	0.01	3.277	0.102	9.4	0.9	1.9	0.1
PB 254	0.57	0.06	3.311	0.271	9.2	1.3	1.9	0.2	0.53	0.04	3.119	0.192	10.0	1.2	2.2	0.9
PB 255	0.60	0.04	3.503	0.215	8.1	1.1	1.7	0.1	0.56	0.04	3.334	0.215	8.9	1.0	1.9	0.2
PB 260	0.65	0.05	3.853	0.396	7.3	0.9	1.4	0.1	0.60	0.06	3.571	0.396	8.3	1.3	1.9	0.3
PB 280	0.64	0.05	3.842	0.429	7.7	0.6	1.5	0.3	0.57	0.03	3.367	0.079	8.9	1.0	1.9	0.2
RRIC 100	0.62	0.05	3.593	0.362	9.5	1.5	1.8	0.3	0.59	0.06	3.413	0.418	9.5	1.5	1.7	0.3
RRIC 110	0.66	0.07	3.989	0.452	8.1	1.4	1.4	0.4	0.62	0.08	3.673	0.463	8.6	1.1	1.6	0.4
IAN 873	0.53	0.02	3.108	0.113	11.0	0.7	2.1	0.2	0.51	0.02	3.017	0.124	11.0	0.8	2.3	0.2
PM 10	0.61	0.08	3.401	0.463	8.7	2.3	1.8	0.5	0.59	0.07	3.334	0.407	9.4	2.2	1.8	0.6
BPM 24	0.64	0.05	3.797	0.327	7.9	0.8	1.4	0.3	0.56	0.04	3.367	0.305	9.8	1.6	1.9	0.1
Nab 17	0.65	0.05	3.940	0.429	8.1	0.9	1.3	0.3	0.58	0.03	3.627	0.373	9.2	0.5	1.6	0.3

TABLE 8. CURE CHARACTERISTICS OF FORTY-THREE CLONAL RUBBERS — MR 100 (40 MIN/140°C) AND RHEOMETRIC (160°C) MEASUREMENTS USING ACS 1 MIX *(CONT'D)*

Clone	Non-CV Rubber								CV Rubber							
	MR 100 (MPa)		Torque modulus ΔT (Nm)		Cure rate (t_{90}–t_2) min		Scorch time t_2 (min)		MR 100 (MPa)		Torque modulus ΔT (Nm)		Cure rate (t_{90}–t_2) min		Scorch time t_2 (min)	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Class IIIA																
RRIM 709	0.65	0.09	4.091	0.678	8.1	1.1	1.5	0.4	0.59	0.01	3.729	0.622	9.2	1.5	1.8	0.4
RRIM 710	0.67	0.06	4.147	0.452	7.9	1.0	1.6	0.3	0.63	0.06	3.797	0.463	8.5	1.1	1.8	0.3
RRIM 717	0.69	0.02	4.181	0.181	7.3	0.9	1.4	0.8	0.63	0.02	3.808	0.102	8.0	0.9	1.7	0.1
RRIM 730	0.58	0.03	3.526	0.203	8.8	0.7	1.6	0.2	0.54	0.02	3.356	0.124	9.7	0.6	1.9	0.1
RRIM 803	0.67	0.03	4.034	0.124	7.1	0.8	1.5	0.1	0.60	0.02	3.503	0.124	8.6	0.6	1.8	0.2
RRIM 804	0.64	0.05	3.808	0.215	8.4	1.2	1.6	0.2	0.60	0.03	3.537	0.136	8.7	0.9	1.9	0.1
RRIM 806	0.64	0.09	3.899	0.633	8.4	2.0	1.7	0.5	0.59	0.06	3.548	0.407	9.5	1.8	1.9	0.4
RRIM 809	0.60	0.08	3.593	0.441	8.6	1.4	1.7	0.4	0.57	0.09	3.447	0.520	9.1	2.1	1.8	0.5
PB 242	0.59	0.06	3.695	0.509	8.6	1.2	1.7	0.4	0.55	0.04	3.334	0.203	9.7	0.9	2.0	0.3
PB 274	0.58	0.05	3.379	0.283	8.9	1.2	1.9	0.4	0.54	0.02	3.153	0.079	9.7	0.4	2.2	0.2
PB 312	0.65	0.09	3.808	0.565	8.5	2.1	1.5	0.4	0.62	0.09	3.571	0.565	9.4	2.0	1.8	0.5
PM 8	0.63	0.06	3.831	0.452	8.5	1.8	1.6	0.3	0.58	0.04	3.458	0.294	9.2	1.2	1.9	0.2
RRIC 101	0.63	0.08	3.740	0.644	8.9	1.6	1.6	0.5	0.61	0.08	3.469	0.509	9.4	1.4	1.9	0.6
RRIC 102	0.64	0.06	3.673	0.463	8.3	1.1	1.7	0.5	0.60	0.06	3.514	0.475	8.3	1.2	1.9	0.4
L.S.D.		0.06		0.437		1.5		0.35		0.06		0.370		1.43		0.34
S.D.		0.05		0.384		1.3		0.30		0.05		0.325		1.26		0.30

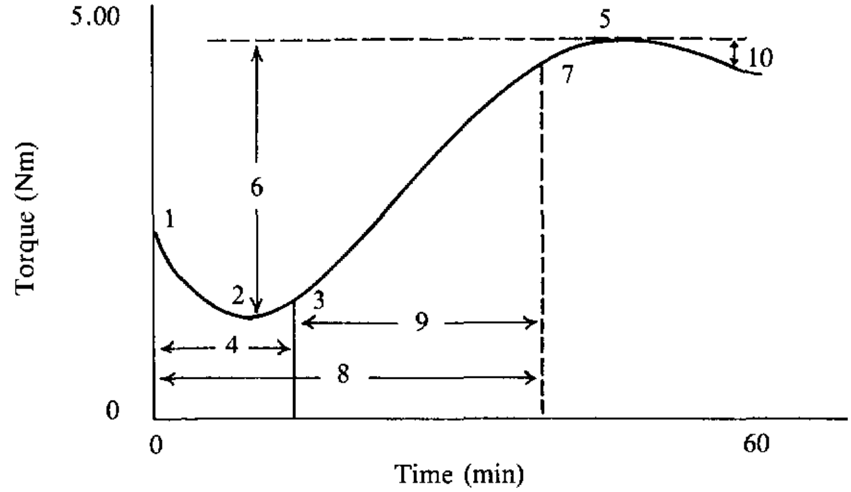

Figure 6. A rheometric cure curve showing the initial viscosity (1), minimum torque, T_{min} (2), induction point (3), induction or scorch time, t_2 (4), maximum torque, T_{max} (5), $\Delta T = (T_{max} - T_{min}$ (6), optimum torque, T_{90} (7), optimum cure time, t_{90} (8), cure rate $(t_{90} - t_2)$ (9), and reversion (10).

(Figure 6). The important cure characteristics include the scorch or induction time (t_2), rate of cure $(t_{90} - t_2)$ (where t_{90} represents the optimum cure time), and the change in torque (ΔT) during vulcanisation, as denoted by $(T_{max} - T_{min})$.

Results of such measurements using the ACS 1 formulation for the forty-three clonal rubbers are also shown in *Table 8*. For the non-viscosity-stabilised rubbers, the mean ΔT was seen to vary between 3.108 Nm and 4.328 Nm, while the mean cure rate ranged from 6.8 min to 11.0 min, and the scorch time from 1.3 min to 2.1 min. Two clones, PB 217 of *Class I* and IAN 873 of *Class II* were observed to show relatively lower curing efficiencies, having mean ΔT values of 3.209 Nm and 3.108 Nm respectively, which were accompanied by slower cure rates of 10.5 min and 11.0 min and longer scorch times of 2.0 min and 2.1 min respectively. Five other clones: RRIM 728 *(Class II)*, RRIM 709, RRIM 710, RRIM 717 and RRIM 803 (all of *Class IIIA*), on the other hand, exhibited comparatively faster and better curing behaviour, as reflected in the cure rates of less than 8.1 min and their higher ΔT values of more than 4 Nm. Differences in their scorch times were however not as apparent.

The corresponding viscosity-stabilised clonal rubbers were generally found to be slower and less efficiently cured, as indicated by slower cure rates of 8.0 min to 11.0 min, a lower mean ΔT range of 3.017 Nm to 3.808 Nm, and scorch times which varied between 1.6 min and 2.3 min. These represent a change of 0%–31% in cure rate, 2%–18% in ΔT and 0%–37% in scorch time. These effects are evidently due to the treatment by hydroxylamine neutral sulphate (HNS) in the preparation of the CV rubbers[44]. The mechanism involved is not yet clear.

The associations of lower ΔT values with slower cure rates and longer scorch times, and *vice-versa*, suggested the existence of certain relationships between these characteristics. Statistical analysis subsequently carried out revealed that ΔT is negatively correlated with both cure rate and scorch time *(Figures 7* and *8)*, while the cure rate is positively correlated with scorch time *(Figure 9)*.

For a given vulcanisation formulation — the ACS 1 in this case — differences in vulcanising behaviour between NR samples can be ascribed to the presence of various naturally occurring

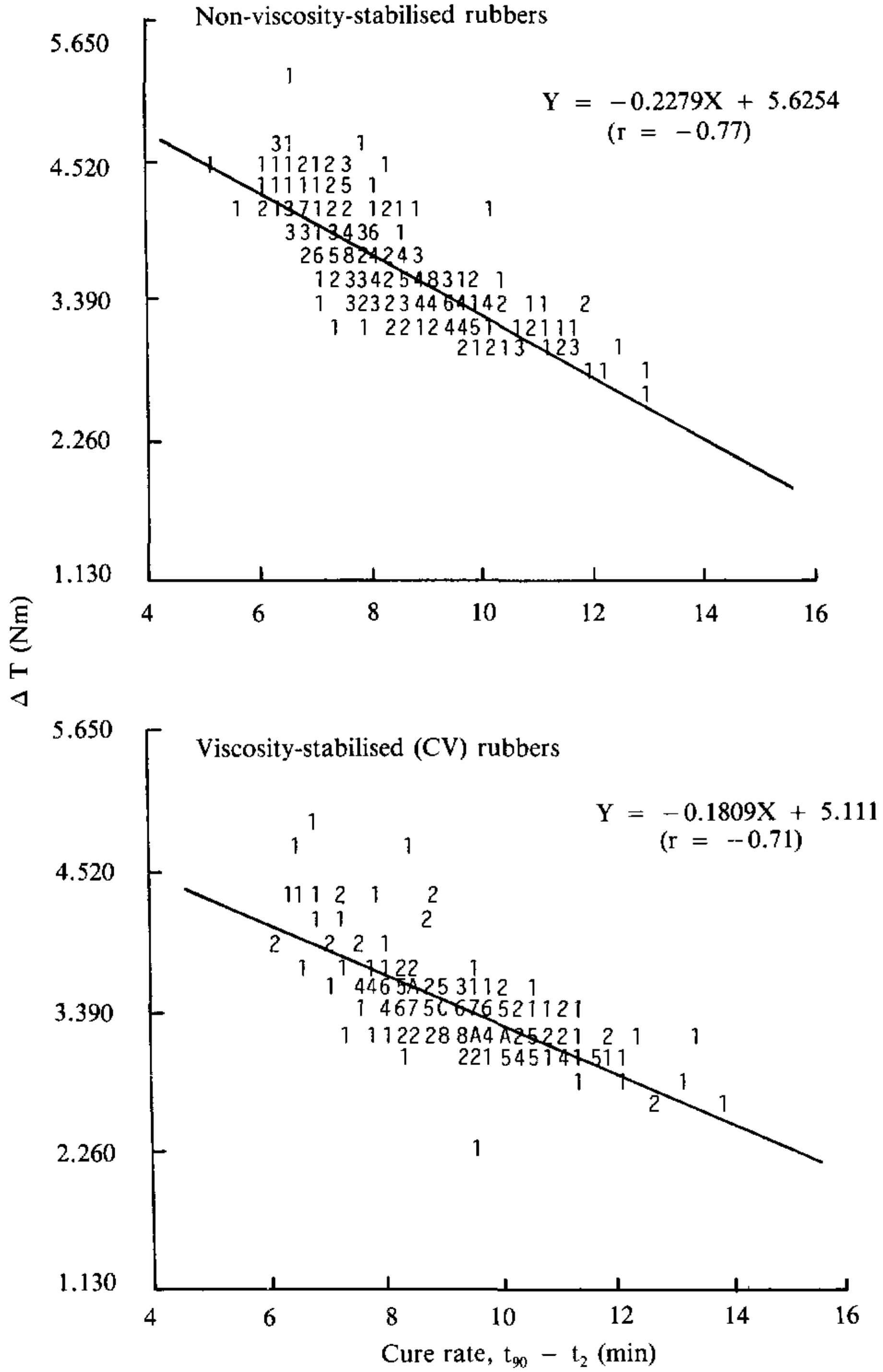

Figure 7. ΔT versus cure rate ($t_{90} - t_2$) for non-viscosity-stabilised and the corresponding viscosity-stabilised rubbers of forty-three clones vulcanised at 160°C using ACS 1 mix. The numbers 1–9 stated in the graph denote the number of points plotted in a given position. Similarly the alphabets A, B, C .... L represent 10, 11, 12 .... 16 points respectively.

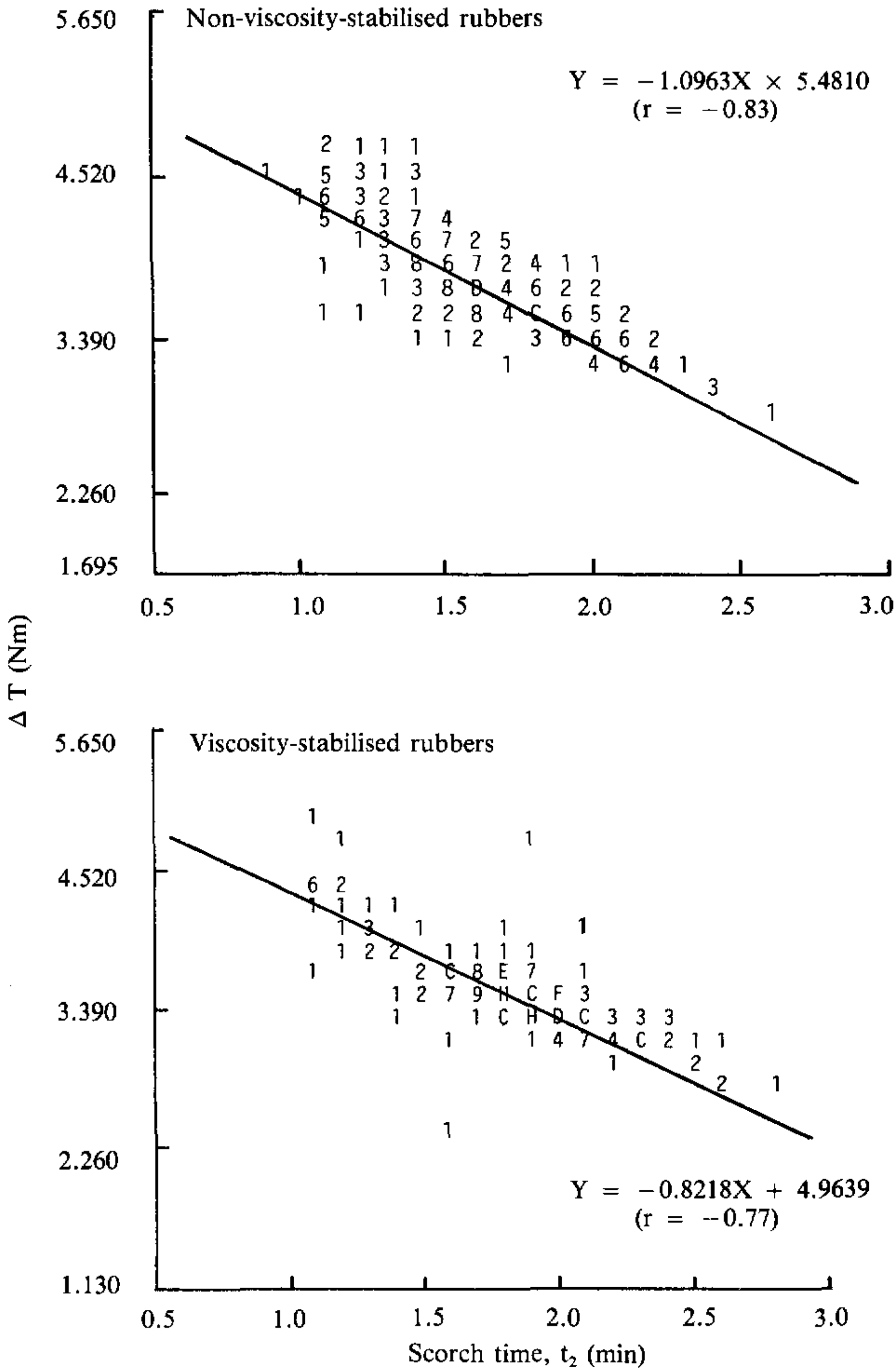

Figure 8. ΔT versus scorch time (t_2) for non-viscosity-stabilised rubbers and the corresponding viscosity-stabilised rubbers cured at 160°C using the ACS 1 mix, for forty-three clones. The numbers 1–9 stated in the graph denote the number of points plotted in a given position. Similarly the alphabets A, B, C .... L represent 10, 11, 12 .... 16 points respectively.

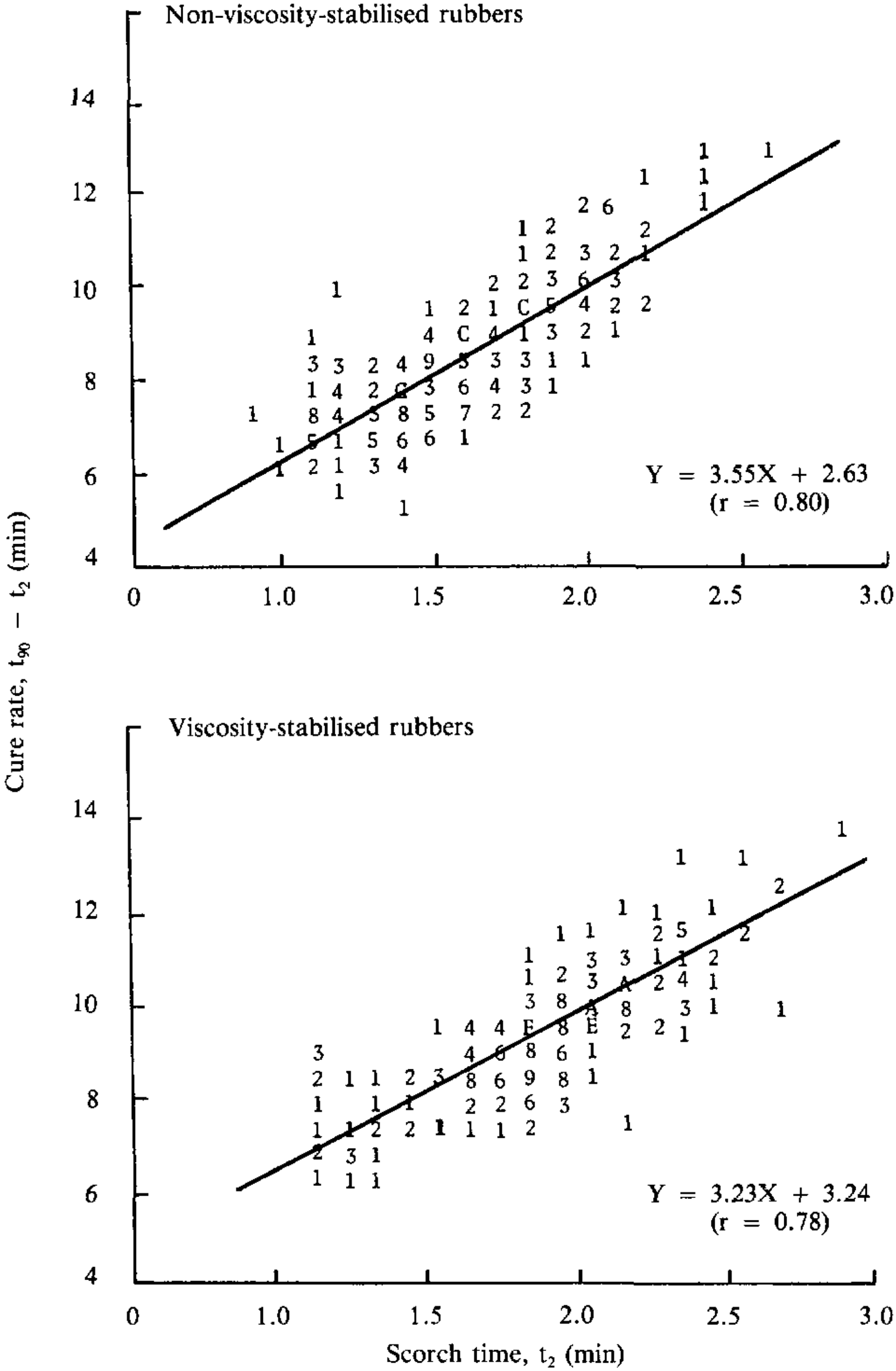

Figure 9. Relationship between cure rate, ($t_{90} - t_2$) and scorch time (t_2), of non-viscosity-stabilised and viscosity-stabilised rubbers vulcanised at 160°C using ACS 1 mix, for forty-three clones. The numbers 1-9 stated in the graph denote the number of points plotted in a given position. Similarly the alphabets A, B, C .... L represent 10, 11, 12 .... 16 points respectively.

non-rubbers, the qualitative and quantitative compositions of which not only vary between clones but are also influenced by the procedures used in the coagulation process; for example, the pH of coagulation, type of coagulant, degree of dilution of latex prior to coagulation, time of maturation of coagulation and subsequent washing of the rubber. In the present study, in which all the rubber samples tested were prepared using the same processing procedure, the differences observed should be due only to clonal variation in their non-rubber contents. Hydrolysis products of lipids, such as the free fatty acids and amines, and certain nitrogenous substances present in latex are known to affect cure[38-41,45]. Correlations between the nitrogen contents of the clonal rubbers and their corresponding cure parameters have however been found to be insignificant. This is not unexpected since not all the naturally occurring nitrogenous materials exert an influence. Furthermore, while amines like ethanolamine and choline, which are hydrolysis products of phospholipids, and arginine[45] (a basic amino acid) accelerate cure, other amino acids such as cystine, tyrosine, glutamic acid and alanine give rise to slower cure rates[40].

Correlation between vulcanisate modulus and rheometer torque measurements. Analyses of the two sets of cure data showed the following correlations between MR100 and ΔT, where the relaxed modulus values had been corrected to those corresponding to Mooney viscosity 40 of the unvulcanised compounds[5], and $\Delta T = T_{max} - T_{min}$ (in Nm) *(Figure 10).*

For non-CV rubbers,

$$\text{MR100 (corrected)} = 0.1324\ \Delta T + 0.1299 \quad (r = 0.91)$$

For CV rubbers,

$$\text{MR100 (corrected)} = 0.1389\ \Delta T + 0.0998 \quad (r = 0.87)$$

These findings confirm that a relationship exists between ΔT and MR100, as reported earlier by Bristow[46] who showed a correlation between these two properties obtained from different grades of SMR rubbers as well as rubbers prepared by different processes. His equation is however not strictly comparable to the ones shown above, since the condition for his ΔT measurements were somewhat different although a temperature of 160°C was used in both cases: a change in torque at 10 min as compared to minimum torque, *i.e.* $\Delta T = T_{10} - T_{min}$ (in inch lb) was adopted in that study instead of the difference between maximum and minimum torques.

As indicated earlier, MR100 values may be predicted from the torque measurements or *vice-versa* using these relationships, provided the conditions of measurements are the same as those employed to produce the correlations.

CONCLUSION

Various important technical properties which relate to the qualities of latex concentrate and bulk rubber have been studied for forty-three clones of *Hevea brasiliensis.* The findings reported should provide useful guidelines to the characteristics of each of the clones, even though there may be some variations if the same clones were to be grown in different sites, due to the influence of soil and environmental conditions.

The study has shown that there are clonal differences in almost all the properties examined. Determination of the dry rubber content of fresh latex indicated that except for *Class IIIA* clones, RRIM 710 and PB 274 which gave relatively low d.r.c., all the other clones yielded latices with average to high rubber contents. Provided excessive dilution by water during the latex collection process does not cause the d.r.c. to drop below 25%, all the clonal latices can be processed *via* centrifugation to give latex concentrates.

In the form of high ammonia concentrates, eighteen clones exhibited poor inherent stabilities as reflected in low MST values. Addition of an anionic surfactant at 0.02% to improve these values effected different responses by different clones. While a large number of the unstable clones responded well showing an elevated MST of higher than the specification limit of 650 s after three months' storage, the

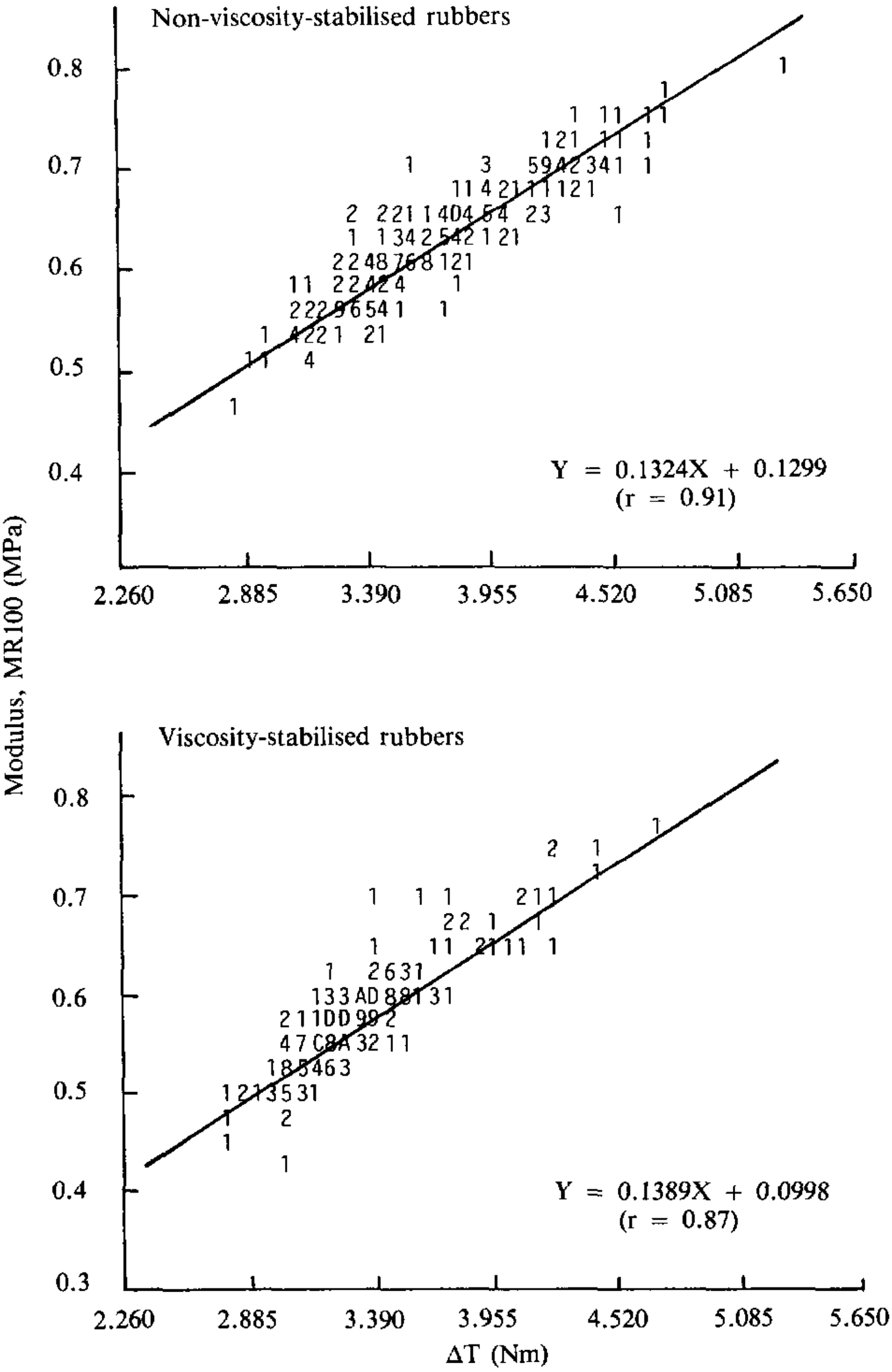

Figure 10. Correlation between MR100 of non-viscosity-stabilised and viscosity-stabilised rubbers vulcanised at 140°C for 40 min and ΔT of the same rubber cured at 160°C, both using the ACS 1 formulation, for forty-three clones. The numbers 1–9 stated in the graph denote the number of points plotted in a given position. Similarly the alphabets A, B, C .... L represent 10, 11, 12 .... 16 points respectively.

MST values of a few other clones remained low. The cause of this is believed to be related to differences in the surface properties of the rubber particles between clones. Apart from the MST measurements, all properties satisfied the specifications set out in *ISO 2004*.

Unstable latex concentrates are often associated with high VFA numbers and hence high KOH numbers. Significant correlation was however not observed between MST and KOH for these clonal latices.

When processed as SMR WF, though not on a large factory scale, the findings have indicated that most of the modern clones produce medium to hard rubbers, and few yield soft rubber. In addition, rubbers from the RRIM clones generally have low to medium viscosities, while those from the PB clones tend to have relatively high viscosity. As all the dry rubber properties tested met the specification requirements for SMR production, non-viscosity-stabilised rubber grades can be prepared from latices of all these clones, twenty-five of which consistently yielded light-coloured rubbers. On the other hand, only fifteen clones were found to be suitable for the production of the viscosity-stabilised grade, SMR CV 60. However, the other clones could also be converted into CV grades by blending with rubbers of appropriate high or low viscosity.

Good correlations were obtained between Mooney viscosity and initial Wallace plasticity of the clonal rubbers for both non-CV and CV rubbers. Their cure characteristics, expressed in terms of ΔT and MR100, were also significantly correlated.

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