

Heveacrumb Process

J. E. MORRIS

Rubber Research Institute of Malaya, Kuala Lumpur, Malaysia

The Heveacrumb process for comminuting natural rubber coagulum of all types to facilitate the production of a wide range of products has gained acceptance by the natural rubber producing industry and by consumers. The flexibility of the process is now appreciated in relation to other comminution processes and a logical judgement can now be made from the ease of processing and product acceptability. The recent development and experience gained in producing various forms of Heveacrumb are described.

No other method of processing natural rubber from plantation and smallholding has achieved such rapid acceptance and production growth as 'Heveacrumb' since its invention in 1964 (SEKHAR AND CHIN, 1967). The versatility of the process and the technical quality of the raw rubbers produced has contributed significantly to the producer acceptance of the process and the consumer acceptance of the product. The process of mechano-chemical comminution—Heveacrumb—has been described elsewhere (SEKHAR *et al.*, 1965).

The process is essentially the milling of wet rubber coagulum between a series of grooved steel rolls; strong shearing forces are exerted by the differential speeds and close nip of the rolls, and the addition of a tiny quantity of an incompatible oil (castor oil has proved the most suitable) allows the rubber to break into crumbs instead of webbing together into a crepe. The crumbs are firm and discrete enough to allow rapid drying in a deep-bed through-circulation dryer.

Pilot-scale production started in 1964; by 1965, prototype commercial equipment with the capacity of processing 2 tons of Heveacrumb per day was designed and installed at the Experiment Station of the Rubber Research Institute of Malaya. Technological evaluation by the consuming industry led to immediate and heavy demands, necessitating increased production at the Experiment Station, followed in mid-1966 by the establishment of four commercial factories. By 1968,

another twenty-two factories were in production and plans for another score are well advanced. Rubbers such as Heveacrumb produced by new processing methods have excellent physical properties, coupled with a uniformity that was hitherto difficult to attain by conventional processing methods. Uniformity and consistency however require processing to be carried out in large factories with bulking facilities and also a complement of trained technical supervisory staff (GRAHAM AND MORRIS, 1966).

The rubber producing industry in Malaysia may be divided into six sectors:

- individual ('unassisted') smallholders;
- partly assisted smallholders (State Development Schemes);
- fully assisted smallholders (Federal Land Development Authority);
- proprietary estates;
- large 'agency house' estates; and
- remillers.

The Institute undertook in 1965 to provide assistance in the establishment and operation of one Heveacrumb factory project in each of these sectors of the industry. In June 1967 an Institute factory operating on latex supplies from unassisted smallholders came on stream, followed immediately by another factory processing latex from partly assisted smallholders. The first factory for fully assisted smallholders is scheduled to start production next year. The Institute also assisted in the establishment of a number of factories for estates, both large

TABLE 1. PROPERTIES OF HEVEACRUMB PREPARED BY ACID COAGULATION AND ASSISTED BIOLOGICAL COAGULATION (ABC) COMPARED WITH RSS

Property	Heveacrumb SMR H-5L Acid coagulation		Heveacrumb SMR H-5L ABC coagulation		RSS SMR H-5
Raw rubber properties					
Dirt*, % wt	0.002		0.003		0.005
PRI	91		84		86
Volatile matter, % wt	0.16		0.13		0.68
Ash, % wt	0.19		0.16		0.18
Nitrogen, % wt	0.43		0.38		0.49
Copper, p.p.m.	1		1		1
Manganese, p.p.m.	1.3		1.0		1.4
Acetone extract, % wt	3.18		3.47		3.23
Mooney viscosity (V_R) ML 1 \div 4' at 100°C	72		77		76
TC strain, %	83		68		69
Tread compound properties† (Banbury model 00C)					
Curative boosting, %	—	8	—	2	—
Energy consumption kWh					
Pre-mastication stage	0.233	0.229	0.233	0.266	0.223
Mixing stage	0.552	0.553	0.542	0.520	0.546
Total	0.785	0.782	0.775	0.755	0.769
Mooney scorch at 120°C, min	25	26	25	23.5	24
Vulcanisate properties at optimum cure					
Cure time at 140°C, min	30	30	30	30	30
Tensile strength, kg/cm ²	253	261	261	259	260
Elongation at break, %	564	547	567	552	549
Modulus M 300, kg/cm ²	102	113	111	112	115
Hardness, IRHD	61.5	64	63.5	64	65
Resilience, %	66.6	66.8	67.1	67.1	66.2
Relaxed modulus, kg/cm ²	17.5	19.0	18.5	19.1	19.1
Tear strength, kg	28.5	35.5	37	35	34.3
De Mattia flex life, kc to Grade C	53	63	60	67	70
Akron abrasion loss, ml/1000 rev	0.123	0.126	0.132	0.127	0.125
Goodrich heat build-up temperature rise after 60 min, °F	18	16.5	16	16.5	20.3
Aged 14 days at 70°C					
Retention of tensile strength, %	92	92	92	91	91
Elongation at break, %	467	487	470	463	462
Modulus M 300, kg/cm ²	146	147	153	153	153

*Retained on A.S.T.M. 325 mesh

†For details of compound and mixing see *Appendix 1*

and small, and the remilling industry. Heveacrumb produced from all these factories has been sold to Standard Malaysian Rubber specifications (RUBBER RESEARCH INSTITUTE OF MALAYA, 1965) and the production in the month of July 1968 was of the order of 4000 tons.

This paper reviews the experiences in the various processing stages, the evaluation of properties, and the reactions of consumers to Heveacrumb produced in Malaysia.

LATEX PROCESSING METHOD AND PROPERTIES

For many years natural rubber has been sold on the world markets in the form of sheet or crepe, the new presentation methods employ basically different methods of attaining the basic aim of converting latex into a suitable form of rubber that is easy to handle, dry and compress. It is essential to retain the native excellence of the polymer: the properties of the rubber may be altered substantially by changing the methods of coagulation, by too much washing, or by excessive mechanical working etc. (SEKHAR, 1967). The Heveacrumb process has been used successfully with auto-coagulation and Assisted Biological Coagulation (ABC) (JOHN, 1966), as well as with the conventional acid coagulation. However, auto-coagulation requires a period of three days to effect complete agglomeration, is difficult to manage when anti-coagulants are used, and the product becomes sensitive to oxidation by trace metals such as copper (RUBBER RESEARCH INSTITUTE OF MALAYA, 1967); some of the rubber fails to coagulate and is lost and the end-product has a rather high Mooney viscosity; auto-coagulation has therefore not been adopted commercially in the Heveacrumb factories. The ABC process, in which coagulation is speeded by the addition of molasses or pineapple juice, has removed many of the disadvantages of auto-coagulation, retaining however the high Mooney viscosity and faster curing characteristics associated with it. Technological evaluation of commercial preparations of these rubbers made experimentally at the Institute have been conducted recently (GREENSMITH, 1967). Comparative properties of Heveacrumb

prepared by these methods are compared with RSS 1 in Table 1.

Data are also included for compounds in which the sulphur and accelerator curatives are boosted by a small percentage to compensate for the progressively slower cure of the acid coagulated, the CV and LV rubbers. Comparison of the adjusted cure data shows that the properties of the vulcanisates from each type of rubber are very closely similar.

Coagulum Grades of Heveacrumb

The process for manufacturing Heveacrumb from estate cuplump, tree lace and 'bucket lump' has been described by GRAHAM AND MORRIS (1966). At the R.R.I.M. Experiment Station a process of successive granulation, milling and crumbling was most satisfactory; and SMR H-5 grade rubbers have been produced consistently (Table 2). Many producers have adapted existing machinery for the crumbling of these types of coagula: scrap washers, macerating creepers and granulators have all proved useful.

TABLE 2. MEAN VALUES OF TEST DATA ON HEVEACRUMB PRODUCED FROM FIELD COAGULUM AT R.R.I.M. EXPERIMENT STATION OVER A TEN-MONTH PERIOD

Property	Batch number			
	1-50	51-100	101-150	151-200
Dirt*, % wt	0.030	0.028	0.021	0.021
Volatile matter, % wt	0.21	0.19	0.20	0.23
PRI	80	77	78	82
Nitrogen, % wt	0.38	0.34	0.39	0.39
Ash, % wt	0.20	0.15	0.14	0.22
Copper, p.p.m.	1.4	1.0	1.2	1.3
Manganese, p.p.m.	1.2	1.1	1.4	1.0
TC strain, %	58	59	57	58

*Retained on A.S.T.M. 325 mesh

TABLE 3. TYPICAL INSPECTION DATA* ON SHIPMENTS OF BROWN CREPES FROM REMILLING FACTORIES A AND B DURING THE PERIOD 1963-1964

Test		Factory A		Factory B	
		2X thin brown crepe	3X thin brown crepe	2X thin brown crepe	3X thin brown crepe
Number of samples		24	113	20	20
Dirt†, % wt	Max.	0.287 (0.133)	0.513	0.480 (0.188)	0.901
	Min.	0.083 (0.035)	0.274	0.147 (0.020)	0.485
	Mean	0.177 (0.080)	0.456	0.254 (0.077)	0.736
Ash, % wt	Max.	0.80 (0.63)	0.85	0.70 (0.51)	1.20
	Min.	0.48 (0.31)	0.62	0.55 (0.27)	0.84
	Mean	0.57 (0.46)	0.72	0.59 (0.36)	0.96
Acetone extract, % wt (mean)		1.75	1.85	2.14	2.05
Copper, p.p.m. (mean)		3.5 (< 5)	2.8	5.0 (< 5)	3.0
Manganese, p.p.m. (mean)		13.6 (< 5)	17.1	13.5 (< 7)	26.5
TC strain, %	Max.	83	100	80	90
	Min.	67	75	67	77
	Mean	77	84	73	83

* Figures in parenthesis are similar data for Heveacrub SMR 20 made at the same factories in 1968, from similar raw materials.

† Retained on A.S.T.M. 325 mesh

TABLE 4. EFFECT ON PRI OF THE PRODUCT BY SOAKING LOTS OF COMMERCIAL FIELD COAGULA IN 0.5% PHOSPHORIC ACID SOLUTION FOR 2 HOURS

Daily sample	PRI of untreated sample	PRI of phosphoric acid treated sample
1	52	73
2	42	68
3	31	70
4	61	71
5	55	76
6	33	62

Commercial processing in estates has generally followed one of two strategies: some producers achieve the SMR 5 standard by careful

sorting and separate processing of different types of field coagulum; others, aiming for SMR 20 standards, blend all their materials before processing the mixture. Some aspects of such methods are described in another paper (PIKE AND RAMAGE, 1969).

Smallholders' coagulum is usually pre-milled, especially if blending with wet sheet coagulum is required. The type of blending adopted usually depends on the level of resistance to oxidation (Plasticity Retention Index) that is required. If a remiller wishes to produce a rubber with a high PRI, then wet sheet can be blended with lower grades. By such judicious blending of high grade cuplumps, wet sheets and lower grades, both SMR 5 and SMR 20 with a range of PRI values can be produced. The raw materials available in West Malaysia are such that only an insignificant proportion of the lowest grade SMR 50 will be available. It is interesting in this context to compare the quality of remillers' produce in two remilling factories during the years 1963-64 and the

present period. *Table 3* gives the properties and makes a comparison between crepe rubbers produced there in 1963-64 and the SMR M-20 rubbers produced in mid-1968.

The results indicate in no uncertain manner the improved properties of the new type of rubber. The full SMR test data for the two remilling factories are presented in *Appendices 2* and *3* and show the small range of day-to-day variability that may now be expected since the adoption of the Heveacrumb process.

The lowest grade SMR 50 is usually produced from imported low quality materials that are sorted and blended before crumbing. This blending procedure gives a very uniform product and the full test data shown in *Appendix 4* illustrate this clearly. There is an immediate economic advantage of such a blended grade of rubber to the consumers for they receive a product that can be directly used without any further blending operations in their own factory.

The oxidisability of lower grades of unknown and variable origin, has been further reduced by treatment with oxalic or phosphoric acids (SEKHAR, 1965; SMITH AND SEKHAR, 1966), although properties of rubber that has already been oxidised remain unimproved. Oxalic acid treatment has shown anomalous effects on the ageing properties of the vulcanisate, but phosphoric acid is now recommended for routine use by estates and remillers; in addition to improving oxidisability resistance of raw rubbers, it has beneficial effects on the properties of the vulcanisate. The solution may be used repeatedly for the treatment of several batches (WATSON, 1969).

Table 4 shows the improvement in level and uniformity in PRI of successive daily lots of a remiller's production when phosphoric acid treatment is employed.

Production Cost

A new process for the preparation of dry rubber can only be attractive if it is simple, versatile and adaptable to existing machinery. It must also be economic in comparison with conventional methods. Cost comparisons are difficult to prepare because of the extreme

variability between one location and another. For example, an increase in the distance that latex needs to be carried for processing adds to the cost of chemicals as well as to the transport charges. If these increased costs are met by setting up subsidiary coagulation stations, then a price has to be paid in the form of additional supervision costs or an additional variability of the product. For this reason, the breakdown of costs* in *Table 5* are best used to gain an idea of comparative costs without placing undue weight on the absolute values presented. The figures given do not include the costs of supervisory management, which can also vary very considerably in different situations. It is important to note that the Heveacrumb and other new presentation methods lend themselves to very large-scale operation and allow the employment of much more highly qualified technologists and supervisors. Ten years ago the largest estate factory in Malaysia producing dry rubber processed only 8 tons per day, and very few achieved

TABLE 5. OPERATING COSTS* FOR HEVEACRUMB FACTORIES

Item	Latex		Coagulum	
	Estate factory	Converted factory for smallholders' latex	Estate factory	Remilling factory
Labour	0.31	0.95	0.85	0.85
Drying and power	0.83	0.73	2.07	1.44
Water and light	0.07	0.35		
Acid and chemicals	0.71	1.11	nil	nil
Upkeep	0.15	0.07	-	-
Packing	0.92	0.77	1.09	1.13
Total	2.99	3.98	4.01	3.42

* In Malaysian cents/lb

TABLE 6. PRODUCTION COST (M ct/lb) OF RSS, CREPE AND HEVEACRUMB

Item	Heveacrumb SMRH-5L	RSS*	Heveacrumb SMR5 or 20	Brown crepe
Labour	0.31	0.95	0.85	1.97
Fuel and power	0.83	0.75	2.07	2.10
Light and water	0.07	0.12		0.91
Acid and chemicals	0.71	0.33	nil	0.20
Packing†	0.12	0.43	0.12	0.21
Upkeep	0.15	0.22	0.25	0.31
Total	2.19	2.80	3.29	5.70

*Average of three representative 'agency house' estates

†Not materials

half that quantity; today a single factory produces more than 30 tons of Heveacrumb each day and factories of two or three times that capacity are being planned.

Capital Costs

It has been difficult to estimate capital and maintenance costs when new processes have been introduced into existing factories and when conventional machinery has been modified for new uses. It is now becoming clear that not only does investment in a large factory give more efficient and cheaper production, but the best quality machinery pays a dividend in increased throughput and reduced 'down time' for maintenance. Using good quality equipment, it is possible to erect a factory that will produce 30 000 lb of Heveacrumb from latex each day for a capital cost of M\$160 000 (exclusive of site works and coagulating equipment); a similar factory to produce RSS would cost M\$224 000. If it is necessary to handle a mixed crop of latex and coagulum totalling 40 000 lb per day, a Heveacrumb factory may be expected to cost M\$235 000; conventional facilities for RSS and crepe production would

be 50% more expensive. Comparative operating costs are given in *Table 6* for latex rubbers where there is little difference, but crepe production costs are significantly higher than those for Heveacrumb.

Versatility of the Process

In addition to processing a variety of raw materials into a high quality product at competitive costs, the Heveacrumb process lends itself to the production of a number of specially modified rubbers:

1. *Heveacrumb CV*. Natural rubber undergoes hardening during transport and storage, often to an extent that necessitates a pre-mastication process in the user's factory. SEKHAR (1960, 1961 and 1964) elucidated the mechanism of this reaction and showed that the effect could be inhibited by the addition of small quantities of hydroxylamine hydrochloride. Natural rubber so treated can be stabilised at the viscosity obtained at the tree (CHIN, 1969); Heveacrumb CV produced commercially has a Mooney viscosity within the range 50–75, the range of rubber from individual producers usually falling within a narrow range of only

TABLE 7. PROPERTIES OF HEVEACRUMB CV PRODUCED AT THE THREE R.R.I.M. FACTORIES OVER A PERIOD OF TWO YEARS

Source	Mooney Viscosity (V_H) ML 1 + 4' at 100°C		
	Maximum	Minimum	Mean
R.R.I.M. Expt. Station factory			
No. 1 source	61.0	55.0	58.3
No. 2 source	71.0	61.0	68.0
No. 3 source	61.5	57.5	59.5
No. 4 source	68.0	60.5	64.2
Rantau factory			
Total bulk	64.5	50.5	53.5
Meru factory			
Total bulk	64.0	51.0	56.7

TABLE 8. PROPERTIES OF HEVEACRUMB SMR H-5CV AND HEVEACRUMB SMR H-5LV COMPARED WITH HEVEACRUMB SMR H-5L

Property	Heveacrub SMR H-5CV		Heveacrub SMR H-5LV		Heveacrub SMR H-5L	
Raw rubber properties						
Dirt*, % wt	0.001		0.006		0.002	
PRI	88		93		91	
Volatile matter, % wt	0.14		0.55		0.16	
Ash, % wt	0.17		0.16		0.19	
Nitrogen, % wt	0.48		0.40		0.43	
Copper, p.p.m.	1		1		1	
Manganese, p.p.m.	1		1		1	
Acetone extract, % wt	3.37		8.37		3.18	
Mooney viscosity (V_R) ML 1 + 4' at 100°C	60		52		72	
TC strain, %	111		94		83	
Tread compound properties† (Banbury model 00C)						
Curative boosting, %	— 12		— 16		— 8	
Energy consumption kWh						
Pre-mastication stage	—		—		0.233	
Mixing stage	0.555		0.535		0.552	
Total	0.555		0.535		0.785	
Mooney scorch at 120°C, min	25.5		28.5		25	
Vulcanisate properties at optimum cure						
Cure time at 140°C, min	30		30		30	
Tensile strength, kg/cm ²	252		245		253	
Elongation at break, %	577		584		564	
Modulus M 300, kg/cm ²	98		93		102	
Hardness, IRHD	62		61		61.5	
Resilience, %	64.4		63.9		66.6	
Relaxed modulus, kg/cm ²	17.2		16.2		17.5	
Tear strength, kg	34		31.5		28.5	
De Mattia flex life, kc to Grade C	70		60		53	
Akron abrasion loss, ml/1000 rev	0.127		0.128		0.123	
Goodrich heat build-up temperature rise after 60 min, °F	24.5		22		18	
Aged 14 days at 70° C						
Retention of tensile strength, %	92		93		92	
Elongation at break, %	473		493		467	
Modulus M 300, kg/cm ²	148		137		146	

*Retained on A.S.T.M. 325 mesh

†See Appendix 1

10 Mooney viscosity units. Values obtained over a period of two years at three R.R.I.M. factories are given in Table 7. The difficulties encountered in handling and drying CV rubbers made by granulation do not arise with the Heveacrub process. Properties of typical Heveacrub SMR H-5CV rubbers are given in Table 8 (GREENSMITH, 1967). The CV characteristic can also be incorporated into rubbers

prepared from field coagula (CHIN, 1969). Results obtained on 10-ton lots prepared at the R.R.I.M. Experiment Station are presented in Table 9. Hydroxylamine hydrochloride and hydrazine hydrate were used, giving stabilised low and high viscosity products respectively.

2. *Heveacrub LV*. There is a consumer demand for a rubber with an appreciably lower Mooney viscosity than is obtained by the CV

TABLE 9. TEST DATA FOR 10-TON SMR M-20 CONSIGNMENTS OF VISCOSITY-STABILISED AND CONTROL RUBBERS PREPARED FROM ESTATE FIELD COAGULUM AT THE R.R.I.M. EXPERIMENT STATION

Test		Control	Hydroxylamine hydrochloride treatment	Hydrazine hydrate treatment
Number of bales tested		60	60	60
Dirt*, % wt	Max.	0.093	0.066	0.064
	Min.	0.004	0.027	0.020
	Mean	0.048	0.048	0.034
Volatile matter, % wt	Max.	0.34	0.34	0.41
	Min.	0.32	0.12	0.12
	Mean	0.25	0.22	0.24
PRI	Max.	81	78	75
	Min.	61	67	58
	Mean	72	72	66
Nitrogen, % wt	Max.	0.45	0.42	0.45
	Min.	0.25	0.26	0.20
	Mean	0.36	0.34	0.32
Ash, % wt	Max.	0.34	0.25	0.25
	Min.	0.17	0.14	0.12
	Mean	0.24	0.20	0.19
Acetone extract, % wt	Max.	3.54	4.65	3.62
	Min.	2.65	2.91	2.30
	Mean	3.06	3.53	3.03
TC strain, %	Max.	70	70	75
	Min.	61	66	63
	Mean	65	72	68
Compound viscosity (V_c) ML 1 + 4' at 100°C		41	32	
	Max.	—	75	99
	Min.	—	65	76
Mooney viscosity (V_R) ML 1 + 4' at 100°C				
Before storage-hardening		86	71	91
After storage-hardening		99	74	100

*Retained on A.S.T.M. 325 mesh

process. This has been achieved by introducing four parts of a non-staining naphthenic type processing oil into the latex before coagulation; this lowers the Mooney viscosity by approximately 5 units. Crumbling and drying on a commercial scale has presented very little difficulty; production control data from three estate producers of Heveacrumb LV is given in *Table 10*. A comparison of the properties of Heveacrumb SMR H-5LV, Heveacrumb SMR H-5CV and Heveacrumb SMR H-5L is also given in *Table 8*.

TABLE 10. TYPICAL PRODUCTION DATA FROM THREE ESTATE PRODUCERS OF HEVEACRUMB LV OVER A PERIOD OF THREE MONTHS

Estate	Mooney viscosity (V_R) ML 1 + 4' at 100°C		
	Maximum	Minimum	Mean
1	62.0	50.5	57.6
2	66.5	46.0	53.0
3	66.0	50.5	58.1

3. *Peptised Heveacrumb*. Treatment of natural rubber with 0.045% Renacit IV results in cleavage of the polymer chains as a result of peptisation. Physical and dynamic properties of the rubbers are impaired, but certain processing characteristics are introduced that are of great importance in certain sectors of the consuming industry. Peptised rubbers are much softer than LV rubbers, but it has nevertheless proved possible to produce a 10-ton consignment by the Heveacrumb process. Production data for this consignment are given in *Table 11*.

4. *Oil-extended Heveacrumb*. Technical evaluations and consumer surveys have shown that a natural rubber extended with 25% of processing oil would be suitable for most general purposes (CHIN, 1966). Tonnage quantities of oil-extended natural rubber (OENR) have been prepared at the R.R.I.M. Experi-

TABLE 11. PROPERTIES OF HEVEACRUMB PREPARED FROM LATEX PEPTISED WITH RENACIT IV(0.045% ON RUBBER)

Item	Mooney viscosity (V_R) ML 1 + 4' at 100°C	Plasticity Retention Index
Number of bales	315	315
Number tested	103	38
Number of batches	6	6
Minimum batch mean	44	65
Maximum batch mean	55	73
Mean of consignment	48	69

ment Station by the Heveacrumb process, using a light non-staining naphthenic oil. Typical test data are given in *Table 12*. The Mooney viscosity of this type of rubber is about 35, requiring a shallower depth of rubber in the drying beds than for harder products. Physical properties of vulcanisates made from this type of OENR are given in *Table 13* where they are compared with the properties of a control batch oil-extended in a Banbury (SIN, 1968).

Production Statistics

The initial production of Heveacrumb was made from latex or relatively high grade cup-lumps. There was a rapid consumer development in the use of Heveacrumb and a steady off-take of production from commercial factories ensued. The production data of these rubbers and of Heveacrumb CV and LV in Malaysia today are given in *Table 14*. The production statistics of SMR 5, SMR 20 and SMR 50 grades made from field coagulum are detailed in *Table 15*. There is some fluctuation in the quantities produced of these grades due to the changing prices of low grades of RSS and crepe. However, an increasing demand, especially from Japan and Eastern Europe for these uniformly blended rubbers with the specified properties of SMR 20 and SMR 50 grades,

TABLE 12. PRODUCTION CONTROL TEST DATA FOR 6 TONS 25% OENR PREPARED FROM OIL-EXTENDED LATEX AT R.R.I.M. EXPERIMENT STATION

Test	No. of tests	Maximum	Minimum	Mean
Dirt*, %wt	46	0.028	0.003	0.009
PRI	46	100	83	92
Volatile matter, % wt	46	0.91	0.22	0.57
Ash, % wt	46	0.34	0.20	0.28
Nitrogen, % wt	46	0.36	0.28	0.31
Copper, p.p.m.	46	1.4	< 1	< 1
Manganese, p.p.m.	46	2.7	< 1	ca.1
Castor oil, % wt	43	1.2	0.6	—
TC strain, %	5	156	141	147
Mooney viscosity (V _c) ML 1 + 4' at 100°C	5	19.0	16.5	17.9
Mooney scorch, min	5	6.8	5.6	6.2
Mooney viscosity (V _R) ML 1 + 4' at 100°C	180	43	32	38
Acetone extract, % wt	180	29.6	23.8	27.6

*Retained on A.S.T.M. 325 mesh

has led to an accelerated increase in production. Production statistics for Heveacrumb and other comminuted rubbers are given in Table 16.

CONSUMERS' REACTIONS TO HEVEACRUMB

The Technical Advisory Services of the M.R.F.B. have played a major role in publicising new presentation rubbers in consumer factories. Samples have been provided for evaluation in quantities large enough to allow production tests and have paved the way for consumer satisfaction and acceptance. Defects of new process rubbers when encountered have been quickly notified, and while undue publi-

city has been given in certain quarters, such defects arose largely from teething problems associated with new factories. The main disadvantage of the Heveacrumb process is alleged to be the possible use of excess castor oil which may cause surface blooming in certain vul-

TABLE 13. PROPERTIES OF 25% OIL-EXTENDED HEVEACRUMB PREPARED FROM LATEX, COMPARED WITH BANBURY OIL EXTENSION

Property	Heveacrumb 25% OE	Heveacrumb SMR H-5L 25% Banbury OE control
Raw rubber properties		
Dirt*, % wt	0.007	—
PRI	105	—
Volatile matter, % wt	1.6	—
Ash, % wt	0.25	—
Nitrogen, % wt	0.35	—
Copper, p.p.m.	1	—
Manganese, p.p.m.	1	—
Residual castor oil, % wt	0.6	—
Acetone extract, % wt	28	—
TC strain, %	135	—
Mooney viscosity (V _c) ML 1 + 4' at 100°C	35	—
Tread compound vulcanisate properties at optimum cure (Banbury model 00C)†		
Cure time at 140°C, min	40	40
Tensile strength, kg/cm ²	185	190
Elongation at break, %	508	510
Modulus M 300, kg/cm ²	90	94
Hardness, IRHD	58.5	58
Resilience, %	59.3	60.7
Relaxed modulus MR100, kg/cm ²	14.1	14
Tear strength, kg	24.5	24
De Mattia flex life, kc to Grade C	107	55
Akron abrasion loss, ml/1000 rev	0.097	0.107
Goodrich heat build-up temperature rise after 60 min, °F	76	63
Aged 14 days at 70°C		
Retention of tensile strength, %	81	77
Elongation at break, %	406	407
Modulus M 300, kg/cm ²	115	109

*Retained on A.S.T.M. 325 mesh

†See Appendix 1

TABLE 14. PRODUCTION OF LATEX GRADES OF HEVEACRUMB IN MALAYSIA IN LONG TONS

Year	SMR 5L	SMR 5CV	SMR 5LV	Total
1965	199	nil	nil	199
1966	1558	418	66	2042
1967	5367	2045	160	7572
1968*	4136	3146	512	7794
July 1968	740	821	135	1696

* First 6 months

TABLE 16. PRODUCTION OF SMR HEVEACRUMB AND OTHER SMR AND NON-SMR COMMUNUTED RUBBERS IN LONG TONS

Year	Heveacrumb All SMR	Other comminuted forms	
		SMR	Non-SMR
1963	—	—	790
1964	—	—	2 155
1965	430	—	3 770
1966	5 892	90	6 935
1967	16 425	2 275	13 440
1968*	13 796	12 756	6 750†

* First 6 months

† Estimated

canisates. However, only five examples of this defect have ever been authenticated, and in each of these instances, the rubbers were used without technical defect to the finished product. Moreover, it is now possible to replace 0.7% by weight of castor oil with only half that quantity of a mixture of castor oil with zinc stearate (RUBBER RESEARCH INSTITUTE OF MALAYA, 1968a), and no complaint has been received for the last two years. A rapid check method has been developed that allows process control in the factory and limits addition of castor oil to a maximum of 0.5%

TABLE 15. GRADES OF HEVEACRUMB PREPARED FROM FIELD COAGULUM IN MALAYSIA IN LONG TONS

Year	SMR 5	SMR 20	SMR 50	Total
1965	83	147	1	231
1966	1768	2068	14	3850
1967	3408	5445	nil	8853
1968*	1751	3546	705	6002
July 1968	165	1400	604	2169

* First 6 months

by weight (RUBBER RESEARCH INSTITUTE OF MALAYA, 1968b). More precise laboratory analytical methods have been developed by R.R.I.M. and N.R.P.R.A. (CHIN AND YEO, 1966; DAVIES AND TUNNICLIFFE, 1967).

High volatile matter content in initial batches of new presentation block rubbers, inducing unpleasant odours, led to a number of genuine complaints. There has been a reluctance on the part of producers to appreciate the need for complete drying prior to compacting. Inspection procedures for determining moisture contents have been introduced into the factories and difficulties on this aspect rarely reoccur (GRAHAM AND MORRIS, 1966).

From time to time, complaints of contamination have been received; these have usually been due to adventitious contamination in transit. Improved packing and shipping conditions are rapidly overcoming these drawbacks. General factory cleanliness and the use of metal detectors have been advocated to avoid any chance of gross contamination. There have been several complaints regarding the adherence to SMR specification other than volatile content, but it is gratifying to be able to record that in no single case has any complaint been proven to be genuine.

All types of products have been manufactured from Heveacrumb including aircraft tyres, engine mountings, adhesives, tennis balls, golf ball threads, and without exception, in all these uses consumer experience has been satisfactory or enthusiastic. In particular there have been advantages in easier handling, greater uniformity, increased processing efficiency and cleanliness. One manufacturer has turned his entire NR usage to Heveacrumb SMR H-5L. Heveacrumb SMR H-5L has also been used as a reference standard in several countries.

Reduction in processing costs has repeatedly been encountered; Heveacrumb SMR H-5L has been found to give an appreciably lower peak load during processing than RSS 1; reduction in pre-mastication time on open mill and cooler running on the mill has also been reported. CV Heveacrumb reduces mastication even more, and instances have been reported where pre-mastication has been reduced from 10 to 6 minutes savings outweighing the premium on the rubber. In addition to the saving of pre-mastication time and the avoidance of using extra equipment for such a procedure, factory rejects are reported to be substantially reduced. Savings with LV Heveacrumb are reported to be similar to those of CV Heveacrumb.

Heveacrumb pre-coagulum grades have also received acceptance on the grounds of ease of handling and uniformity. In comparison with RSS 2, one consumer found that SMR 20 Heveacrumb was twice as easy to pass through the strainer. In general, consumer acceptance of new presentation rubbers (block rubbers) is growing and these processes will undoubtedly help to halt the encroachment of synthetic rubber into areas where natural is traditionally used.

CONCLUSIONS

A sufficient tonnage of Heveacrumb has now been produced and consumed to confirm that it is a form of natural rubber with excellent characteristics and properties. It has proved to be satisfactory in products where tack, processing behaviour, good dynamic properties and ageing resistance are of paramount importance. Acceptance by manufacturers of the

latex grades and coagulum grades is taking place at an increasing rate as evaluation proceeds and increasing supplies become available. The CV and LV concepts introduced into the Heveacrumb process have been shown to be of great advantage to the consumers.

The Heveacrumb process is sufficiently versatile to process all forms of rubber and latex with economies in capital and processing costs while at the same time maintaining high quality, uniformity and consistency.

ACKNOWLEDGEMENT

The author gratefully acknowledges the assistance and help of Mr. D.J. Graham, Mr. Chin Peng Sung, Dr. H.W. Greensmith, Dr. A.A. Watson, Mr. Sin Siew Weng, Mr. C.A.K. Salgado, Mr. N.M. Pillai and many other members of the Chemistry Division for their direct and indirect help in the preparation of this paper.

The assistance of the Technical Advisory Service of the Malayan Rubber Fund Board is acknowledged for their accurate reports on the comments received from manufacturers' factories on these developments.

REFERENCES

- CHIN, P.S. (1966) Versatility of the Heveacrumb process — applications to oil-extended and constant viscosity natural rubber. *Plrs' Bull. Rubb. Res. Inst. Malaya No. 86*, 111.
- CHIN, P.S. (1969) Viscosity-stabilised Heveacrumb. *J. Rubb. Res. Inst. Malaya*, 22(1), 56.
- CHIN, P.S. AND YEO, O.K. (1966) Private communication. Rubber Research Institute of Malaya.
- DAVIES, J. AND TUNNICLIFFE, M.E. (1967) Determination of castor oil in Heveacrumb rubber by thin-layer chromatography. *J. Chromat.*, 30, 125.
- GRAHAM, D.J. AND MORRIS, J.E. (1966) Manufacture of Heveacrumb. *Plrs' Bull. Rubb. Res. Inst. Malaya No. 86*, 130.
- GREENSMITH, H.W. (1967) Heveacrumb rubbers for the Research Institute of the Tyre Industry, Moscow, U.S.S.R. *Chem. Div. Rep. No. 69, Rubb. Res. Inst. Malaya*.
- JOHN, C.K. (1966) Biological coagulation of *Hevea* latex using waste carbohydrate substrates. *J. Rubb. Res. Inst. Malaya*, 19(5), 286.
- PIKE, M. AND RAMAGE, J. (1969) Uniformity and processability of new type natural rubbers. *J. Rubb. Res. Inst. Malaya*, 22(1), 26.
- RUBBER RESEARCH INSTITUTE OF MALAYA (1964) Preliminary details of the mechano-chemical crumbling process. *Chem. Div. Leaflet. Rubb. Res. Inst. Malaya*.

- RUBBER RESEARCH INSTITUTE OF MALAYA (1965) Standard Malaysian Rubbers: specifications and sampling procedure for producers. *Pirs' Bull. Rubb. Res. Inst. Malaya* No. 78, 81.
- RUBBER RESEARCH INSTITUTE OF MALAYA (1967) Low PRI rubbers. *Chem. Div. Inf. Circ. No. 29, Rubb. Res. Inst. Malaya*.
- RUBBER RESEARCH INSTITUTE OF MALAYA (1968a) Modified crumbling agent for latex Heveacrumb manufacture. *Chem. Div. Inf. Circ. No. 31, Rubb. Res. Inst. Malaya*.
- RUBBER RESEARCH INSTITUTE OF MALAYA (1968b) Factory control test for castor oil in Heveacrumb. *Chem. Div. Inf. Circ. No. 32, Rubb. Res. Inst. Malaya*.
- SEKHAR, B.C. (1960) Degradation and cross-linking of polyisoprene in *Hevea brasiliensis* latex during processing and storage. *J. Polym. Sci.*, **48**, 133.
- SEKHAR, B.C. (1961) Inhibition of hardening in natural rubber. *Proc. nat. Rubb. Res. Conf. Kuala Lumpur 1960*, 512.
- SEKHAR, B.C. (1964) Improvements in or relating to the stabilisation of natural rubber. *Br. Pat. No. 965757*.
- SEKHAR, B.C. (1965) Improvements in or relating to the preparation of lower grade natural rubbers and skim rubbers. *Br. Pat. Applic. No. 48702/65*.
- SEKHAR, B.C. (1967) Malaysian natural rubber—new presentation methods. Address to the Malaysian Branch of the Institution of Rubber Industry in Kuala Lumpur in April 1967.
- SEKHAR, B.C. AND CHIN, P.S. (1967) Improvements in or relating to the processing of natural rubber. *Br. Pat. No. 1 075 235*.
- SEKHAR, B.C., CHIN, P.S., GRAHAM, D.J., SETHU, S. AND O'CONNELL, J. (1965) Heveacrumb. *Rubb. Dev.*, **18**(3), 78.
- SIN, S.W. (1968) Heveacrumb oil-extended natural rubber for the Research Institute of the Tyre Industry, Moscow, U.S.S.R. *Chem. Div. Rep. No. 69 (Suppl.)*, *Rubb. Res. Inst. Malaya*.
- SMITH, J.F. AND SEKHAR, B.C. (1966) Improvements in or relating to the preparations of lower grade natural rubbers and skim rubber. *Br. Pat. Applic. No. 14393/66*.
- WATSON, A.A. (1969) Improved ageing of natural rubber by chemical treatments. *J. Rubb. Res. Inst. Malaya*, **22**(1), 104.

DISCUSSION

Chairman: Mr. B. C. Sekhar

Mr. C.W. Thompson suggested that assisted biological or auto-coagulation with perhaps only small additions of acid produced rubber with uniform properties from many clones and saved costs on chemicals and transport. The alternative method to obtain uniformity by bulking field latex involved its preservation with an anti-coagulant, transporting a large volume of water and neutralising the anti-coagulant. Mr. Morris wished he could agree, but experience with smallholders' latex at collecting stations showed that bulking was essential since variations were too great even with assisted biological coagulation. He agreed with the Chairman that it was advisable to bulk greater quantities of latex. When transporting coagulum the weight was not greatly reduced because there was still a large proportion of water in lump coagulated in the field or at the collecting station.

APPENDIX 1. TREAD COMPOUNDS AND BANBURY (MODEL 00C) MIXING CYCLES USED IN THE EVALUATION OF HEVEACRUMB RUBBERS

Item	Auto and acid coagulated Heveacrub SMR H-5L; Heveacrub CV and LV; and RSS	Heveacrub 25% OE	Heveacrub SMR H-5L 25% OE in Banbury
Banbury base stock			
Rubber	95	100	75
HAF black (Acarb)	45	52	53
Dutrex R (Shell)	5	—	—
Dutrex 63 (Shell)	—	—	25
Zinc oxide (ICI Red Seal)	4	4	4
Stearic acid (ICI Rubber Grade)	1.5	1.5	1.5
Nonox HFN (ICI)	1.5	1.5	1.5
Vulcanising ingredients	Masterbatch		
	Standard		
	2%		
	8%		
	12%		
	16%		
RSS 1 Yellow Circle	5	—	—
Sulphur (ICI)	2.5	2.0	2.0
CBS (Monsanto)	0.5	0.4	0.4
Mixing cycle			
Starting temperature, °C	100±2	100±2	100±2
Rotor speed, rev/min	80	80	80
Batch weight, g	2221 (approx. 2000 cc)	2230	2230

BANBURY AND MILL MIXING STAGE SCHEDULE

Time, min	Auto and acid coagulated Heveacrub SMR H-5L and RSS	Heveacrub CV and LV	Heveacrub 25% OE	Heveacrub SMR H-5L 25% OE in Banbury
--------------	---	------------------------	---------------------	--

Banbury schedule

0	Add rubber	Add rubber, powders and black + oil	Add rubber, powders and black	Add rubber, powders and black
1	—	—	—	Add mineral oil in polythene bag
1½	Add powders and black + oil	—	—	—
2	—	Sweep down	Sweep down	Sweep down
2½	—	—	Dump	Dump
3	—	Dump	—	—
3½	Sweep down	—	—	—
4½	Dump	—	—	—

Mill mixing schedule

0	Stock dumped on 24" × 12" rolls at 70±2°C trimmed to 2000 g and banded to cool	Stock dumped on 24" × 12" rolls at 70±2°C and banded to cool
2	Vulcanising masterbatch added and mixed	Sheeted off and 800 g taken on to 12" × 6" rolls at 70°C; sulphur and accelerators added
4½	Finished with three passes rolling and up-ending and one final sheeting pass	Finished with three passes rolling and up-ending and one final sheeting pass

J.E. MORRIS: Heveacrumb Process

**APPENDIX 2. SMR TEST DATA ON PRODUCTION OF HEVEACRUMB SMR M-20
FROM REMILLING FACTORY A, MAY AND JUNE 1968**

Lot size, tons	Dirt*, % wt			Volatile matter % wt			PRI			Nitrogen % wt	Ash, % wt		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean		Max.	Min.	Mean
(May)													
5	0.12	0.08	0.10	0.35	0.29	0.31	76	73	75	0.32	0.58	0.50	0.54
5	0.12	0.07	0.09	0.40	0.33	0.36	76	73	74	0.33	0.54	0.49	0.52
5	0.12	0.06	0.10	0.42	0.31	0.35	80	76	78	0.32	0.46	0.39	0.42
5	0.11	0.08	0.09	0.42	0.31	0.34	78	74	76	0.32	0.59	0.49	0.53
5	0.13	0.08	0.10	0.42	0.33	0.37	78	74	76	0.35	0.54	0.52	0.53
5	0.11	0.05	0.08	0.57	0.29	0.39	80	73	77	0.33	0.63	0.56	0.60
5	0.11	0.09	0.10	0.42	0.31	0.34	74	71	72	0.31	0.51	0.46	0.49
5	0.09	0.04	0.06	0.33	0.22	0.26	79	75	77	0.34	0.45	0.31	0.37
(June)													
5	0.06	0.04	0.05	0.30	0.25	0.24	72	69	70	0.29	0.40	0.37	0.39
5	0.06	0.04	0.05	0.27	0.23	0.25	77	73	76	0.30	0.43	0.38	0.40
5	0.06	0.04	0.05	0.28	0.18	0.24	76	72	74	0.28	0.41	0.38	0.39
5	0.08	0.05	0.07	0.29	0.23	0.26	78	73	75	0.31	0.41	0.37	0.39
5	0.08	0.05	0.07	0.23	0.19	0.21	80	72	76	0.29	0.45	0.42	0.43
5	0.13	0.09	0.12	0.44	0.20	0.35	78	75	77	0.32	0.51	0.44	0.48
Extremes	0.13	0.04		0.57	0.28		80	71			0.63	0.31	
Average			0.08			0.31			76	0.32			0.46

*Retained on A.S.T.M. 325 mesh

APPENDIX 3. SMR TEST DATA ON PRODUCTION OF HEVEACRUMB SMR M-20 FROM REMILLING FACTORY B, MAY AND JUNE 1968

Lot size, tons	Dirt*, % wt			Volatile matter % wt			PRI			Nitrogen, % wt			Ash, % wt			Copper, p.p.m.			Manganese, p.p.m.		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
(May) 25	0.11	0.05	0.07	0.52	0.37	0.44	78	75	76	0.41	0.39	0.40	0.45	0.36	0.40	<5	<5	<5	<5	<5	<5
25	0.10	0.03	0.05	0.36	0.27	0.31	75	68	72	0.44	0.43	0.44	0.40	0.30	0.33	<5	<5	<5	<5	<5	<5
20	0.09	0.04	0.06	0.41	0.30	0.36	74	67	70	0.40	0.39	0.40	0.46	0.39	0.41	<5	<5	<5	<5	<5	<5
20	0.10	0.04	0.07	0.51	0.25	0.37	79	74	78	0.39	0.38	0.39	0.36	0.28	0.32	<5	<5	<5	6	4	5
25	0.09	0.05	0.06	0.34	0.26	0.31	81	72	77	0.42	0.40	0.41	0.35	0.30	0.33	<5	<5	<5	6	4	5
25	0.08	0.03	0.06	0.42	0.32	0.38	78	75	76	-	-	0.40	0.37	0.27	0.33	<5	<5	<5	6	4	5
20	0.09	0.05	0.07	0.50	0.41	0.46	79	74	77	-	-	0.40	0.35	0.33	0.35	<5	<5	<5	6	4	5
25	0.08	0.04	0.06	0.47	0.29	0.36	78	76	77	-	-	0.40	0.41	0.37	0.36	5	2	3	<5	<5	<5
20	0.06	0.05	0.05	0.51	0.29	0.41	81	71	77	0.39	0.38	0.39	0.39	0.33	0.37	4	2	3	6	4	5
20	0.07	0.04	0.05	0.40	0.28	0.36	80	71	74	0.40	0.39	0.40	0.40	0.28	0.33	6	2	3	<5	<5	<5
20	0.07	0.04	0.05	0.37	0.27	0.31	78	73	76	-	-	0.38	0.39	0.31	0.35	3	2	3	6	4	5
25	0.10	0.04	0.06	0.40	0.31	0.35	77	72	74	-	-	0.41	0.44	0.34	0.36	7	2	3	<5	<5	<5
20	0.06	0.03	0.05	0.40	0.37	0.36	78	71	75	0.41	0.39	0.40	0.38	0.32	0.36	4	2	3	<5	<5	<5
25	0.08	0.04	0.05	0.51	0.38	0.40	83	75	79	-	-	0.41	0.36	0.30	0.33	<5	<5	<5	-	<5	<5
(June) 25	0.07	0.02	0.05	0.44	0.35	0.37	72	62	69	0.45	0.36	0.40	0.39	0.28	0.31	<5	<5	<5	5	5	5
25	0.15	0.10	0.12	0.44	0.33	0.38	80	73	77	0.35	0.34	0.34	0.34	0.33	0.34	<5	<5	<5	8	6	7
25	0.16	0.07	0.13	0.40	0.31	0.34	80	71	76	0.34	0.33	0.34	0.51	0.42	0.45	<5	<5	<5	10	6	7
25	0.15	0.11	0.13	0.46	0.32	0.36	85	77	80	0.36	0.35	0.36	0.47	0.42	0.44	<5	<5	<5	9	6	8
25	0.19	0.10	0.14	0.45	0.27	0.34	86	75	79	0.38	0.35	0.37	0.48	0.42	0.46	<5	<5	<5	9	7	8
Extremes Average	0.19	0.02		0.52	0.25		86	62		0.45	0.33		0.51	0.27		7	2		9.9	<5	
			0.08			0.37			76			0.39			0.36			<5			ca.5

* Retained on A.S.T.M. 325 mesh

APPENDIX 4. SMR TEST DATA ON PRODUCTION† OF HEVEACRUMB SMR M-50 AT A REMILLING FACTORY IN JULY 1968

Lot size, tons	Dirt*, % wt			Volatile matter, % wt			PRI			Nitrogen % wt	Ash, % wt			Manganese, p.p.m.		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean		Max.	Min.	Mean	Max.	Min.	Mean
5	0.35	0.26	0.29	0.54	0.33	0.44	67	74	70	0.36	1.11	0.80	0.90	11	9	10
5	0.29	0.22	0.26	0.43	0.36	0.40	74	68	70	0.35	1.05	0.90	0.95	12	11	11
5	0.32	0.20	0.26	0.46	0.34	0.41	76	69	73	0.31	1.02	0.81	0.90	11	10	10
5	0.36	0.23	0.29	0.49	0.34	0.42	77	70	74	0.35	1.14	0.81	0.95	12	10	11
5	0.40	0.23	0.31	0.41	0.31	0.34	76	67	71	0.35	1.19	0.80	0.93	12	10	11
5	0.37	0.26	0.32	0.56	0.40	0.46	73	67	70	0.36	1.05	0.86	0.95	11	11	11
5	0.29	0.24	0.27	0.44	0.29	0.35	71	67	69	0.33	1.03	0.62	0.87	12	11	11
5	0.35	0.25	0.31	0.33	0.28	0.30	71	66	69	0.32	1.33	0.83	1.01	12	9	11
5	0.34	0.21	0.28	0.33	0.28	0.30	74	65	70	0.31	1.11	0.38	0.98	11	10	10
5	0.36	0.30	0.34	0.33	0.24	0.27	70	62	68	0.32	1.13	0.88	0.99	11	10	11
5	0.41	0.29	0.36	0.51	0.26	0.36	71	64	68	0.28	1.19	0.86	1.01	11	10	10
5	0.41	0.28	0.35	0.40	0.29	0.34	74	64	68	0.27	1.11	0.79	0.92	12	11	11
5	0.39	0.32	0.34	0.33	0.23	0.28	70	60	66	0.31	1.28	0.88	1.03	11	10	11
5	0.31	0.21	0.26	0.79	0.36	0.54	71	55	65	0.31	1.03	0.74	0.84	11	10	11
5	0.33	0.22	0.27	0.43	0.31	0.38	73	65	69	0.29	0.84	0.69	0.77	12	11	11
5	0.27	0.23	0.25	0.65	0.38	0.50	77	65	70	0.33	0.97	0.73	0.84	12	10	11
5	0.31	0.21	0.25	0.57	0.47	0.52	75	64	69	0.29	1.06	0.76	0.88	12	11	11
5	0.26	0.18	0.22	0.73	0.43	0.56	68	60	65	0.32	1.10	0.78	0.91	11	9	10
5	0.33	0.22	0.28	0.69	0.35	0.48	70	62	66	0.31	1.12	0.84	0.97	11	9	10
5	0.29	0.20	0.24	0.64	0.36	0.51	70	62	66	0.32	1.06	0.81	0.90	11	10	10
5	0.24	0.17	0.22	0.77	0.42	0.58	70	55	66	0.33	1.04	0.78	0.86	11	9	10
5	0.25	0.20	0.22	0.61	0.45	0.56	73	61	68	0.33	1.02	0.80	0.91	11	10	11
5	0.23	0.18	0.21	0.77	0.51	0.62	73	65	70	0.32	1.00	0.75	0.85	11	10	10
5	0.28	0.20	0.23	0.72	0.40	0.56	70	63	68	0.34	1.01	0.88	0.93	10	9	9
5	0.25	0.12	0.20	0.71	0.35	0.51	74	62	67	0.34	0.95	0.82	0.90	10	9	10
5	0.34	0.20	0.27	0.30	0.17	0.23	62	54	60	0.26	1.09	0.89	1.00	9	9	9
5	0.31	0.19	0.24	0.66	0.23	0.40	68	55	64	0.34	1.02	0.77	0.91	10	9	10
5	0.37	0.18	0.28	0.36	0.22	0.30	66	57	61	0.37	1.15	0.83	1.00	9	8	9
5	0.36	0.25	0.30	0.42	0.24	0.30	68	62	64	0.30	1.27	0.89	1.02	11	9	10
5	0.37	0.24	0.31	0.33	0.18	0.23	68	64	65	0.25	1.22	0.91	1.01	10	9	9
5	0.34	0.21	0.27	0.25	0.18	0.22	72	65	68	0.27	1.08	0.81	0.92	9	8	8
5	0.35	0.25	0.31	0.31	0.19	0.24	71	64	67	0.27	0.96	0.88	0.91	9	8	9
5	0.36	0.23	0.28	0.26	0.20	0.23	69	65	67	0.26	0.96	0.78	0.86	9	9	9
25	0.37	0.26	0.31	0.36	0.23	0.27	66	59	62	0.28	1.14	0.86	0.94	9	8	8
25	0.37	0.17	0.25	0.50	0.22	0.33	69	57	64	0.27	1.20	0.82	0.93	10	8	8
Extremes	0.41	0.12		0.79	0.17		77	54			1.33	0.62		12	8	
Average			0.28			0.39			67	0.31			0.93			10

* Retained on A.S.T.M. 325 mesh

† The copper content on all samples was less than 5 p.p.m.