CHAPTER 3

RESULTS

3.1 Apparent density of oil palm midrib and leafblade

The apparent density of the oil palm midrib was determined by the method in Section 2.1. The results are presented in Table 7 below.

Table 7: The apparent density of oil palm midrib and leaf blades

	Wt. of wet sample (g)	Wt. of dry sample (g)	Apparent density (g/cc)	Mean apparent density (g/cc)
Midrib	25.7	13.8	0.537	
	16.0	9.12	0.570	
	19.6	10.47	0.534	0.547
Leaf blade	40.2	10.2	0.254	
	36.6	9.4	0.257	
	46.7	9.9	0.212	0.241

3.2 Morphological properties of the oil palm midrib, leaf blade and petiole

The morphological properties of the oil palm midrib, leaf blade and petiole were determined by the method described in Section 2.4. Photomicrographs of the fibres can be seen in Plates 3 and 4.

Table 8: Morphology of the midrib, leaf blade and petiole of the oil palm

	Midrib	Leaf blade	Petiole	Trunk*
Average fibre length (mm)	1.82± 0.55	0.89± 0.26	1.71± 0.42	0.96
Average fibre diameter (μm)	15.60± 3.89×10^{-3}	11.06± 2.81×10^{-3}	22.16± 5.82×10^{-3}	29.6
Average cell wall thickness (μm)	11.24± 3.88×10^{-3}	4.58± 2.04×10^{-3}	16.84± 5.64×10^{-3}	20.0
Coefficient of suppleness (%)	72.0	41.4	76.0	67.7
Runkel ratio	0.39	1.41	0.32	0.50
Felting power (L/d)	116.3	80.5	76.9	32.5

Source: * Khoo and Lee (1985)

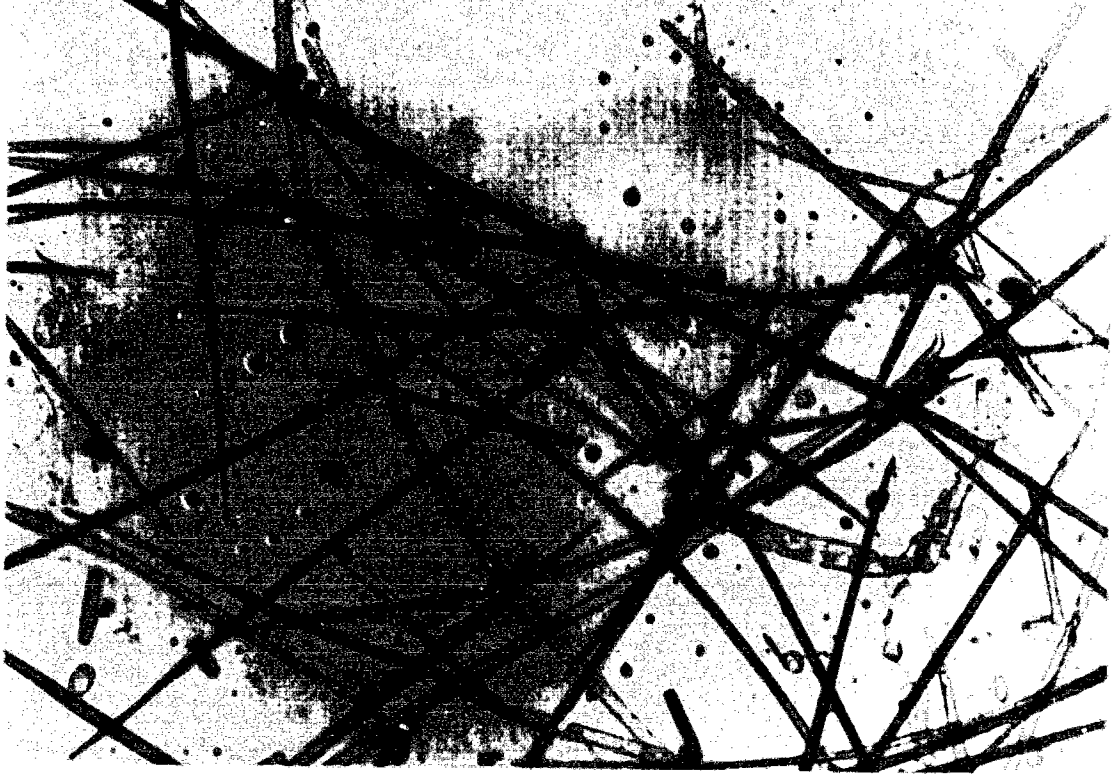


PLATE 3: Photomicrograph (160x) of the fibre from oil palm midrib (stained with safranin-o)

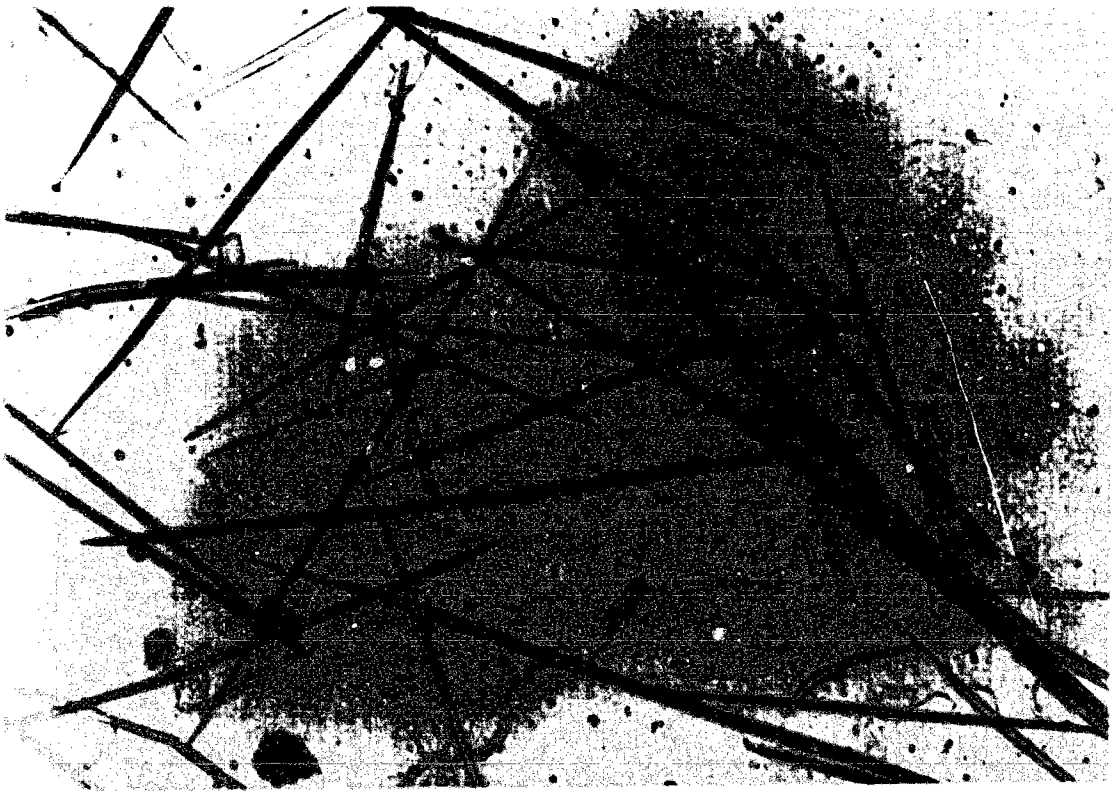


PLATE 4: Photomicrograph (160x) of the fibre from oil palm leaf blade (stained with safranin-o)

Table 9: Fibre dimensions of the oil palm in comparison with some agricultural residues and wood plants

FIBRE	Average length (mm)	Average diameter (μm)	Length/ Diameter
Oil Palm:			
*Midrib**	1.82	15.6	116
*Leaf blade**	0.89	11.0	81
*(Petiole) frond**	1.59	19.7	81
*Trunk***	0.96	29.6	32
Straws and Esparto#	1.1-1.5	9-13	110-120
Rice straw#	1.45	8.5	170
Stalk and reeds#	1.0-1.8	8-20	80-120
Sugarcane fibres#	1.7	20	85
Woody stalks with bast fibres:			
Woody stems#	0.2-0.3	10-11	<30
Bast fibres#	20-25	16-22	>500
Leaf fibres#	6-9	16-18	250-300
Bamboos#	3-4	14	200
Coniferous woods#	2.7-4.6	32-43	750-90
Deciduous woods#	0.7-1.6	20-40	<50

Source: * Khoo, 1989

** Khoo and Lee, 1985

Ibrahim and Fouad, 1973

(Data without symbols are obtained from this investigation while the rest of the data with symbols are used for comparison purposes. Please refer to Table 8).

3.3 Chemical characterisation of the oil palm midrib and leaf blade

The proximate chemical analyses of the oil palm midrib and leaf blade were determined by the methods in Sections 2.5.1 to 2.5.9.

Table 10 shows the results obtained as compared with the data of some monocotyledon species. For comparison, the data on the proximate chemical composition of the oil palm frond and some Malaysian hardwood species are included together with the results in this study in Table 11.

Table 10: Analytical comparison of the oil palm with some monocotyledon species (in percentage based on OD material).

Raw material	Ash	Lignin	Pentosan	α-Cellulose
Oil palm:				
Midrib	0.7	24.5	22.3	44.7
Leaf blade	9.1	30.3	12.2	24.1
Trunk[#]	1.63	22.6	25.9	45.8
Straws and grasses	6-8	17-19	27-32	33-38
Bamboo[*]	1-3	22-30	16-21	50+

Source: # Khoo and Lee, 1985

* Casey, 1952

Table 11: Analytical comparison of the proximate chemical composition of the oil palm to some Malaysian hardwood species (in percentage based on OD material)

Chemical composition	Midrib	Leaf blade	Frond# (petiole)	Malaysian hardwood species*
Moisture (%)	7.8	14.4	-	-
Ash (%)	0.7	9.1	4.48	0.03-2.11
Alkali solubles (%)	23.1	51	33.3	2.60-24.5
Alcohol-benzene (%)	6.5	15.9	8.3	0.60-11.6
Hot water solubles (%)	9.1	30.5	5.0	0.10-14.4
Lignin (%)	24.5	30.3	16.1	12.70-34.2
Pentosans (%)	22.3	12.2	23.4	4.20-20.7
Holocellulose (%)	68.4	46.1	65.5	59.40-85.4
Alpha-cellulose (%)	44.7	24.1	37.4	35.10-54.2

Source: # Khoo, 1989

* Khoo and Peh, 1982

3.4 Studies of the pulping conditions and properties of the soda pulps

3.4.1 Studies of the soda pulps from the oil palm leaves (whole), leaf blade and midrib

The methods for determining the pulping properties are found in Sections 2.7.1, 2.7.5, 2.7.6 and 2.7.7

The pulping conditions and properties of the soda pulps of the leaf blades are tabulated in Tables 12, 13 and 14.

Table 12: **Pulping conditions and properties of the soda pulps from oil palm leaves (whole)**

Active alkali (%)	20
Ratio of liquor to OD material	1:7
Max. temp. (^{o}C)	160
Time to max. temp. (hr)	1.5
Time at max. temp.	2
pH	10.14
Screened yield (%)	9.3
Screenings (%)	-
Kappa no.	16.5

Table 18: Pulping conditions and properties of the soda pulp from oil palm leaf blades

Active alkali (%)	18
Ratio of liquor to OP material	1:7
Max. temp. (°C)	160
Time to max. temp. (hr)	1.5
Time at max. temp. (hr)	2
pH	10.14
Screened yield (%)	10.6
Screenings (%)	1.5
Kappa number	64.9

Table 14: Pulping conditions and properties of the soda pulps from oil palm midrib

Batch No (C):	5	6	7	8	9
Wt. of OD sample (g)	400	400	400	400	400
Active Alkali (%)	14	15	16	17	18
Ratio of liquor to material	5:1	5:1	5:1	5:1	5:1
Maximum temp. (^{o}C)	160	160	160	160	160
Time to maximum temp. (hr)	1.5	1.5	1.5	1.5	1.5
Time at maximum temp. (hr)	2	2	2	2	2
K	11.1	11.9	11.2	12.8	11.1
Screened yield (%)	28.7	44.5	44.2	45.9	43.1
Screenings (%)	24.5	8.5	2.5	0.7	0.8
Kappa number	105.7	90.2	88.1	49.3	46.9

Studies of the pulping conditions and properties of the sulphate pulps

3.5.1 Studies of the pulping properties of the sulphate pulps from oil palm midrib and leaf blades

The methods for determining the pulping properties of the sulphate pulps are found in Sections 2.7.1, 2.7.5 and 2.7.7.

The pulping conditions and properties of the sulphate pulps of the midrib are tabulated in Tables 15 and 16.

Table 15: Pulping conditions and properties of the sulphate pulps from oil palm midrib

Trial No (C):	1	2	3	4
Wt. of OD sample (g)	400	400	400	400
Active alkali (A.A.%)	14	15	16	18
Ratio of liquor to material	5:1	5:1	5:1	5:1
Maximum temp. (^{o}C)	160	160	160	160
Time to maximum temp. (hr)	1.5	1.5	1.5	1.5
Time at maximum temp. (hr)	2	2	2	2
Yield	10.31	10.7	10.9	12.21
Screened yield (%)	40.8	40.7	39.7	39.0
Screenings (%)	4.3	2.8	3	0.5
Kappa number	56.8	25.2	22.9	21.4
Active alkali consumed (%)	13.5	18.8	14.6	16

Table 16: Pulping conditions and properties of the sulphate pulps from oil palm leaf blades

Wt. of OD sample (g)	500
Active alkali (%)	18
Ratio of liquor to OD material	7:1
Maximum temp. (^{o}C)	160
Time to maximum temp. (hr)	1.5
Time at maximum temp. (hr)	2
pH	10.11
Screened yield (%)	9.9
Screenings (%)	0.04
Kappa number	22.2
Active alkali consumed (%)	16.3

3.5.2 Studies of the bleaching conditions and properties of the bleached sulphate pulps of oil palm midrib

The bleaching conditions, yield and brightness were determined according to the methods in sections 2.8, 2.7.5 and 2.10.7 respectively. The results of these studies are tabulated in Table 17 below.

Table 17: Details of bleaching conditions for oil palm mid-rib

Kappa number	21.40
Chlorine on OD pulp (%), 1st stage	5.00
Hypochlorite on OD pulp (%), 3rd stage	1.30
Yield of bleached pulp on OD pulp (%)	92.00
Loss of yield on OD unbleached pulp (%)	8.00
Brightness (%)	79.00

Studies of the pulping conditions and properties of the NSSC pulps of oil palm midrib

The methods for determining the pulping conditions of pulping properties are found in Sections 2.7.1, 2.7.5 ...7.

The pulping conditions and properties of the NSSC pulps tabulated in Table 18 below.

Table 18: Pulping conditions and properties of the NSSC pulps from oil palm mid-rib

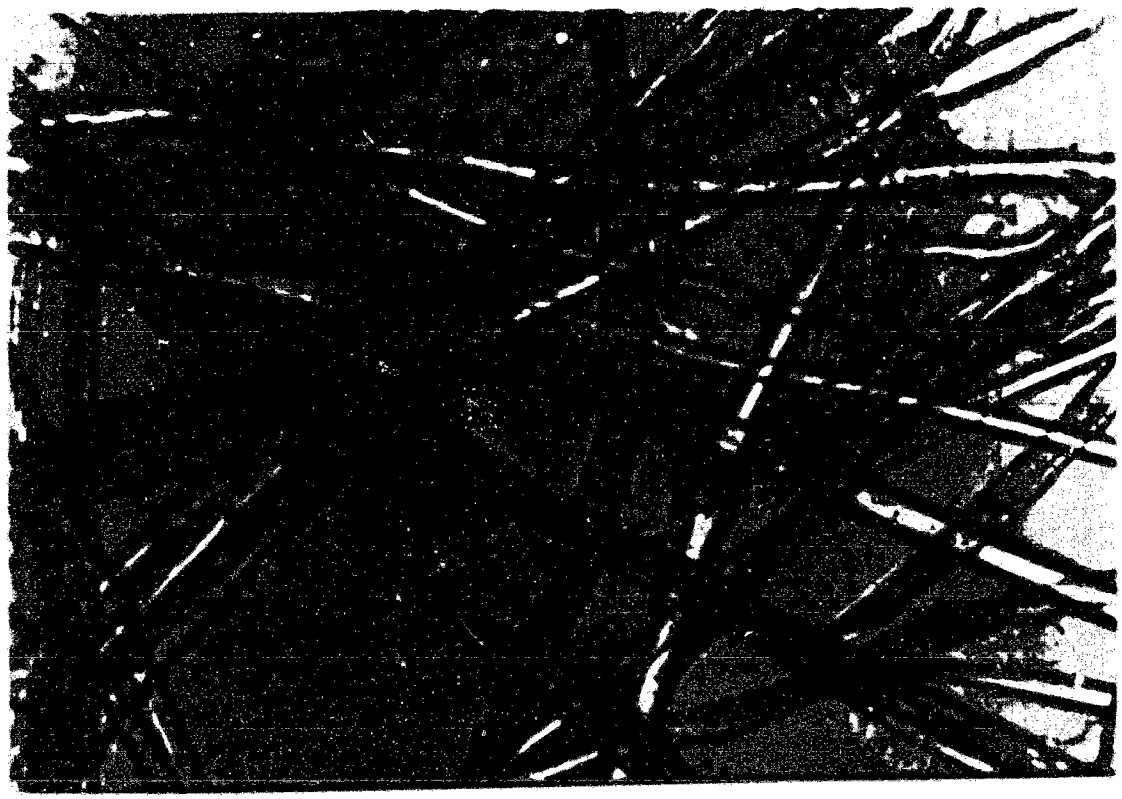
No (C):	10	11	12	13
of OD sample (g)	300	300	300	300
mical charge:				
ium sulphite (%)	4	8	12	16
ium carbonate (%)	6	6	6	6
of liquor to material	7:1	7:1	7:1	7:1
imum temp. (^{o}C)	160	160	160	160
to maximum mp. (hr)	1.5	1.5	1.5	1.5
at maximum mp. (hr)	2	2	2	2
	6.1	7.8	7.6	7.5
eened yield (%)	60.7	57.0	56.0	52.0
reenings (%)	5.9	5.8	3.9	3
ppa number	124.6	120.5	117.0	109.0

Photomicrographs of the unbeaten and beaten NSSC pulps be seen in Plates 5 to 9.

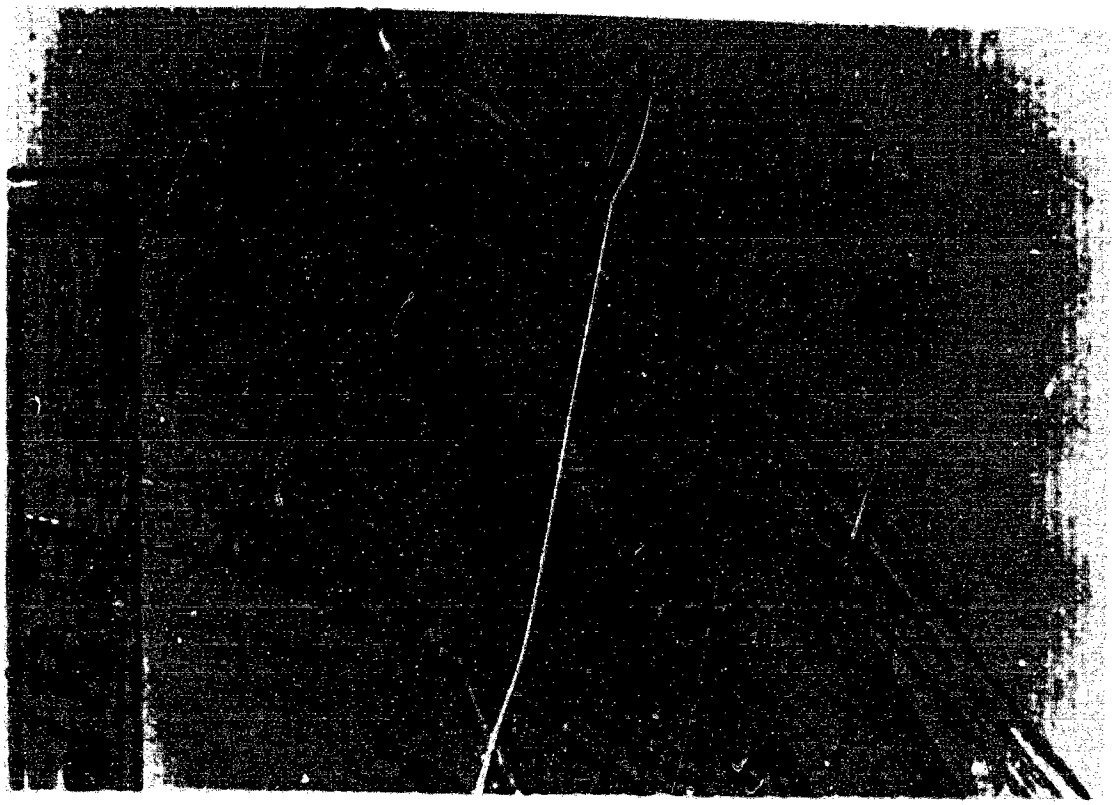
PLATE 5: Photomicrograph (200x) of the NSSC pulp (treatment: unbeaten)

PLATE 6: Photomicrograph (200x) of the NSSC pulp (treatment: 30-minute beating)

[illegible]: Photomicrograph (200×) of the [illegible] pulp (treatment: [illegible] beating)



[illegible]: Photomicrograph (200×) of the [illegible] pulp (treatment: 60-minute beating)



Physical properties of the pulps derived from oil palm midrib

3.7.1 Evaluation of the physical properties of the sulphate pulps derived from oil palm midrib

The physical properties were determined by the methods in Sections 2.10.1 to 2.10.6. Samples of the handsheets are included in this dissertation.

Table 19 presents the results of the physical properties of the sulphate pulps of oil palm midrib. The data in Table 19 is graphically presented in Figures 1 to 10.

Table 15: Sulphite pulp evaluation of the oil palm

Cook No:	Heat. time (min.)	Freeness (ml Cf.	Basis wt. (g/m^2)	Thick (μm)	Bulk (cc/g)	Tear resp. (sec.)	Break. length (km)	Tens. Int ($N.m/g$)	Stretch (%)	TEA Int. (mJ/g)	Impact test. ($mJ.m^2/g$)	Burst Int. ($kPa.m^2/g$)	Double folds (X M. 250 g)
(A) VIRGIN (Unbleached pulp)													
2	30	430	60.5	116	1.91	1	5.7	56	1.7	1767	16.2	4.4	62
	45	380	59.4	110	1.84	2	6.4	63	5.2	1701	15.7	5.5	152
	60	260	58.9	106	1.79	7	6.6	64	5.3	1744	14.7	5.2	135
	75	220	59.3	105	1.77	12	7.0	68	5.4	1922	14.5	5.5	124
3	30	500	59.2	119	1.95	1	5.4	53	4.5	1285	15.2	4.1	62
	60	330	61.5	111	1.81	5	5.7	56	4.8	1430	15.7	4.8	116
	75	240	55.3	107	1.77	9	6.2	61	5.1	1615	14.5	5.1	157
	90	210	57.6	99	1.71	18	6.6	67	5.6	1946	14.7	5.7	215
4	30	540	58.2	120	1.90	1	5.1	52	4.3	1461	17.7	4.1	56
	60	300	58.1	98	1.58	7	6.4	63	4.1	1804	14.8	4.8	152
	75	240	58.2	97	1.57	12	6.6	65	4.7	1953	14.9	4.8	177
	90	230	58.2	95	1.54	17	6.8	66	4.8	2022	16.5	5.1	198
	120	190	58.1	93	1.49	19	6.9	67	4.8	1996	15.9	5.2	203
(Bleached pulp)													
4	30	560	59.2	125	2.14	1	4.1	39	2.3	1751	11.8	3.7	13
	60	350	59.5	120	1.98	2	5.1	50	3.5	1956	12.7	4.5	35
	75	230	58.5	112	1.91	5	5.5	54	3.6	1994	13.5	4.7	48
	90	220	58.2	94	1.61	8	5.7	57	4.3	1974	12.3	4.1	47
	120	190	58.1	95	1.61	12	5.9	55	3.6	1946	13.1	4.3	51
(B) LEAF BLADE													
	60	50	60.6	110	1.61	15	4.5	44	5.2	1290	5.9	3.2	24

Figure 1 : Tear index of sulphate pulp from oil palm midrib at different freeness

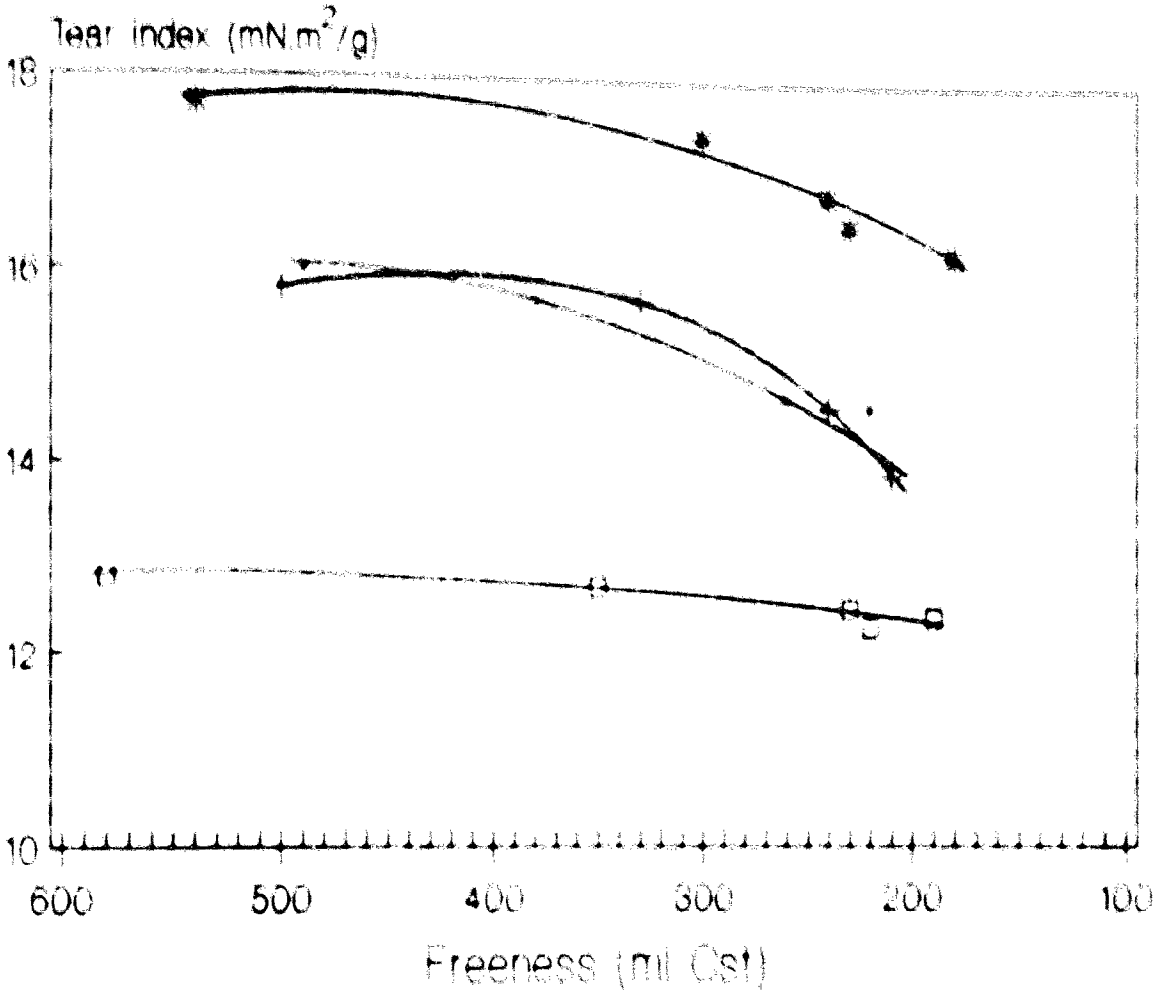


Figure 2 : Burst index of sulphate pulp from oil palm midrib at different freeness

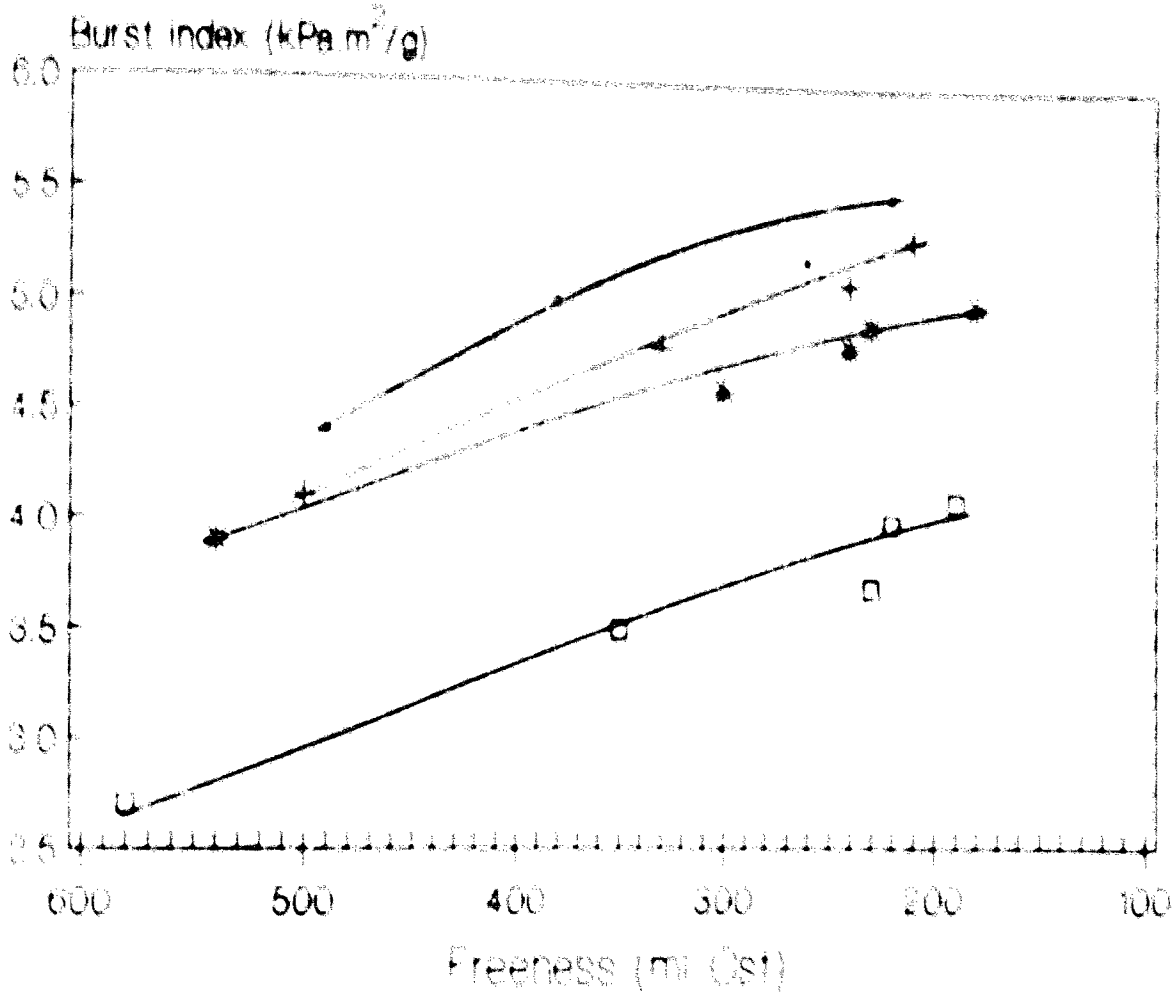


Figure 3 : Tensile index of sulphate pulp from oil palm midrib at different freeness

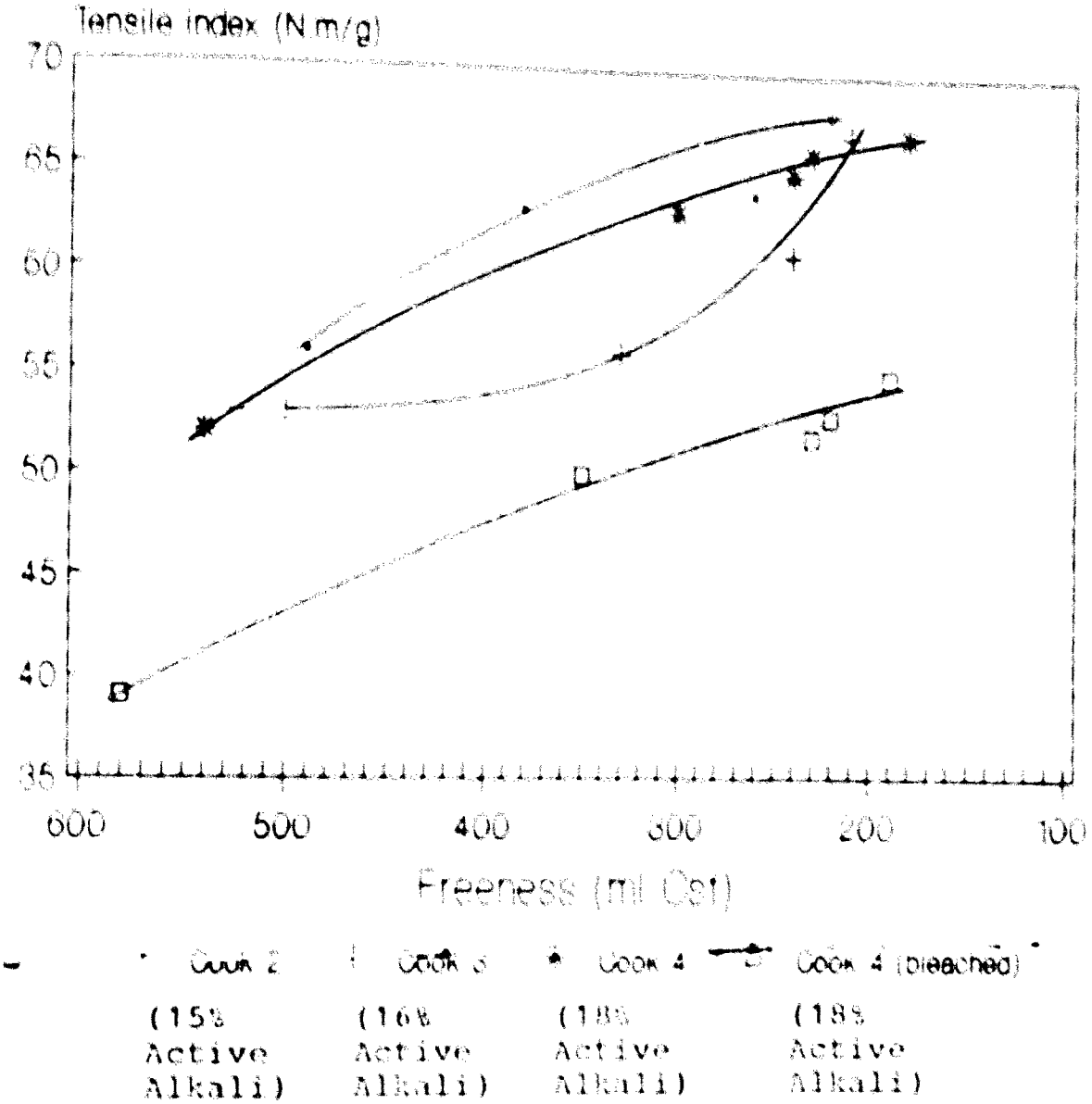


Figure 4 : TEA index of sulphate pulp from oil palm midrib at different freeness

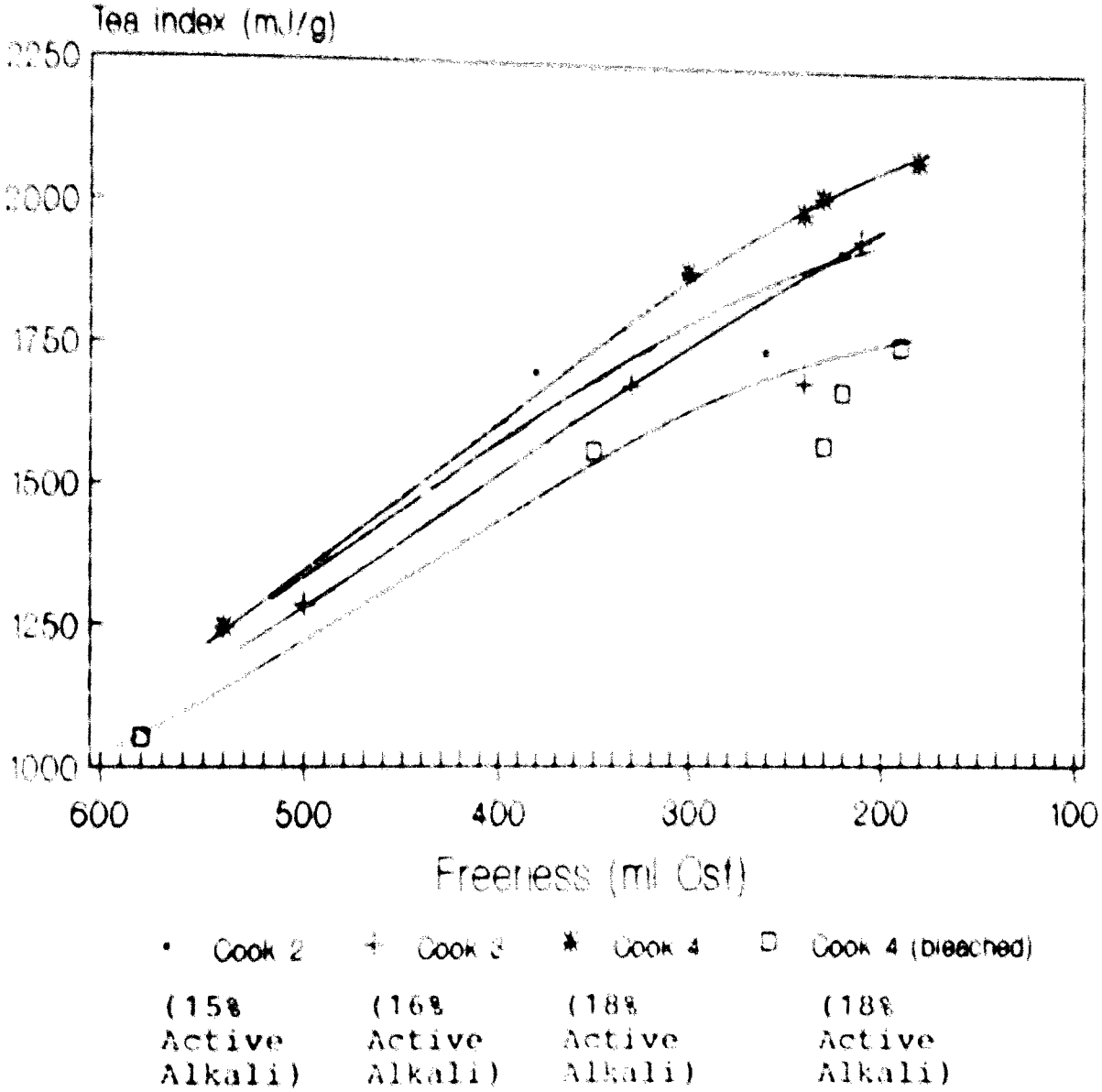


Figure 5 : Breaking length of sulphate pulp from oil palm midrib at different freeness

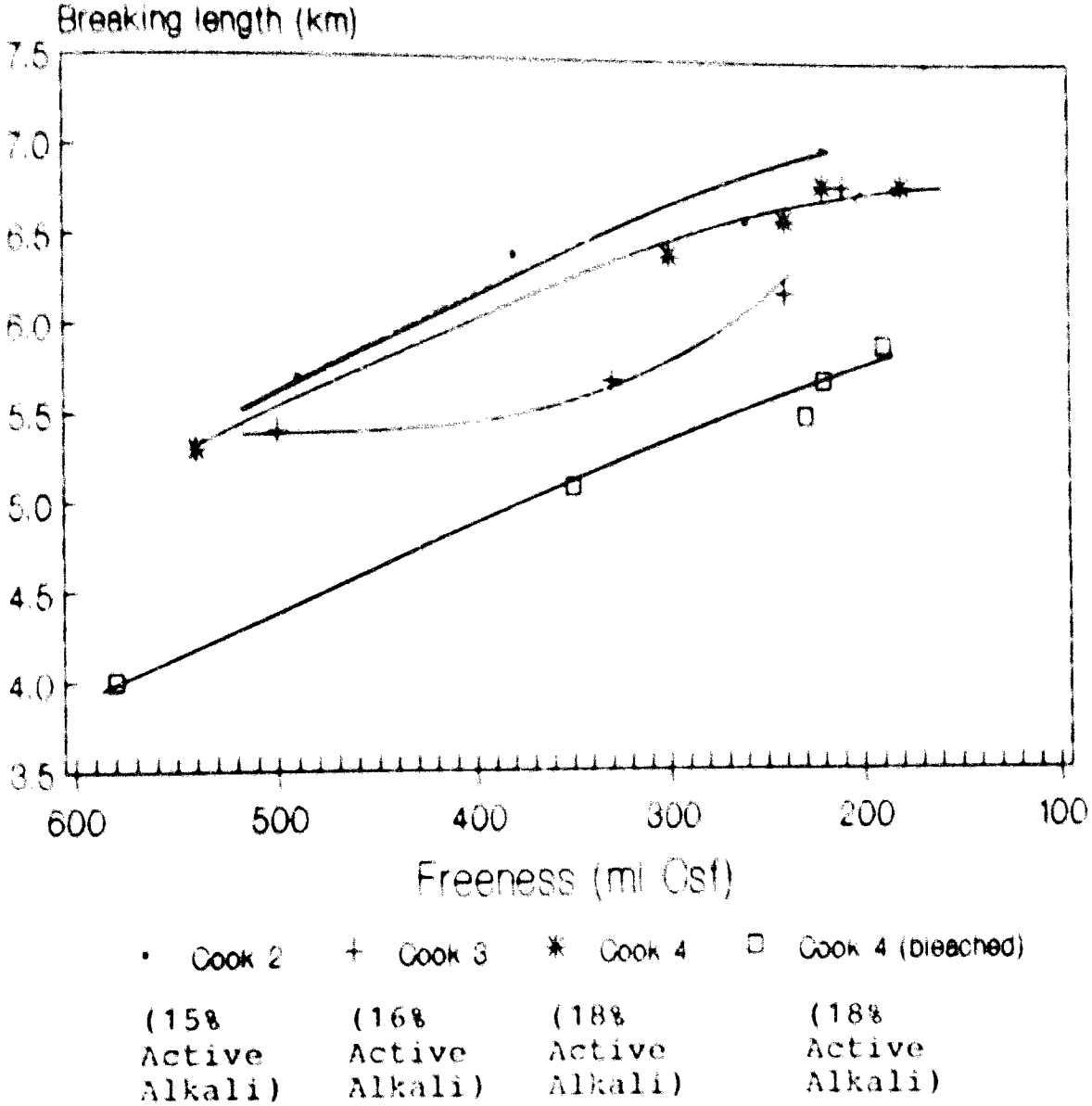


Figure 6 : Double folds of sulphate pulp from oil palm midrib at different freeness

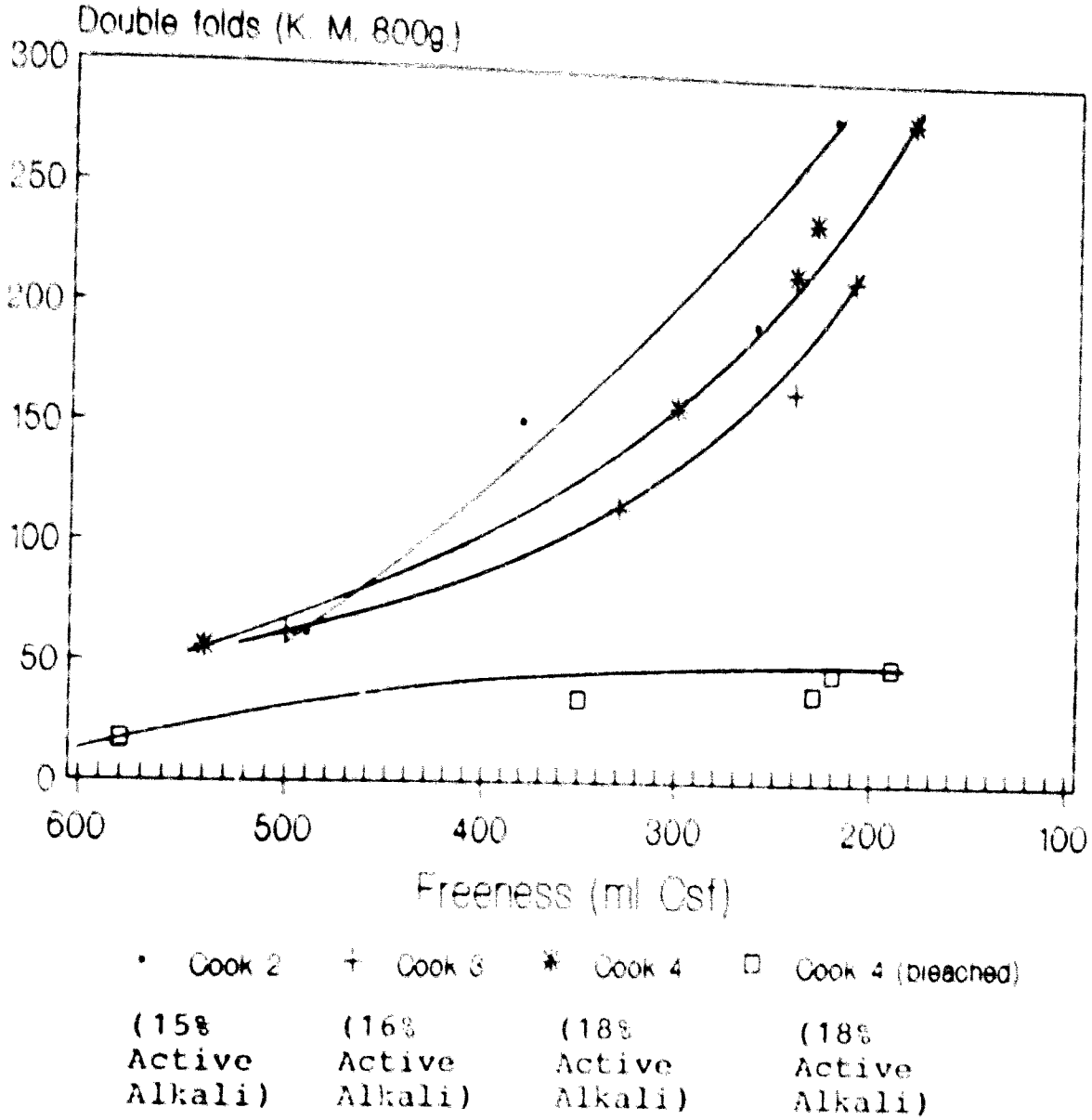


Figure 7 : Stretch of sulphate pulp from oil palm midrib at different freeness

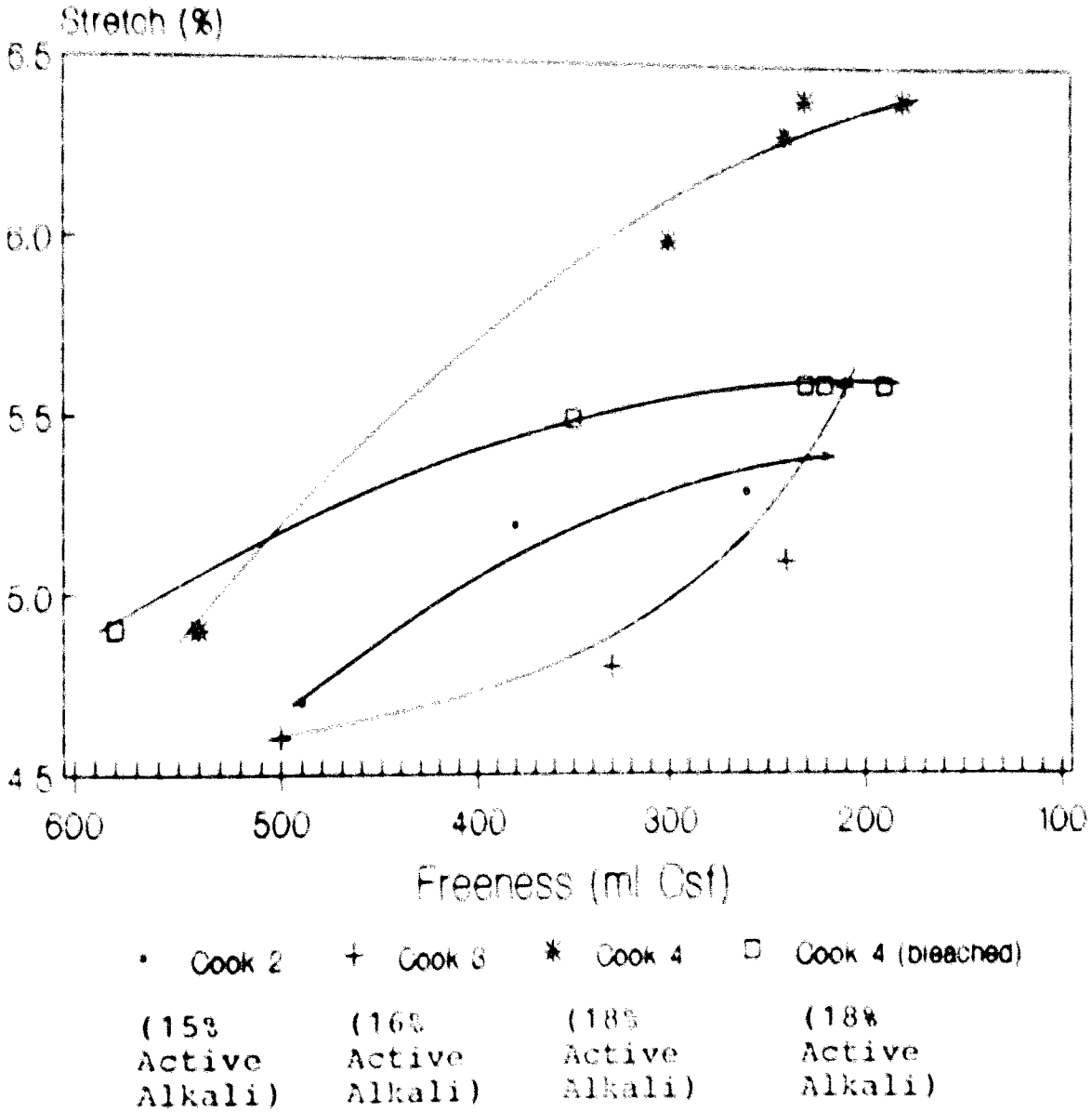


Figure 8 : Air resistance of sulphate pulp from oil palm midrib at different freeness

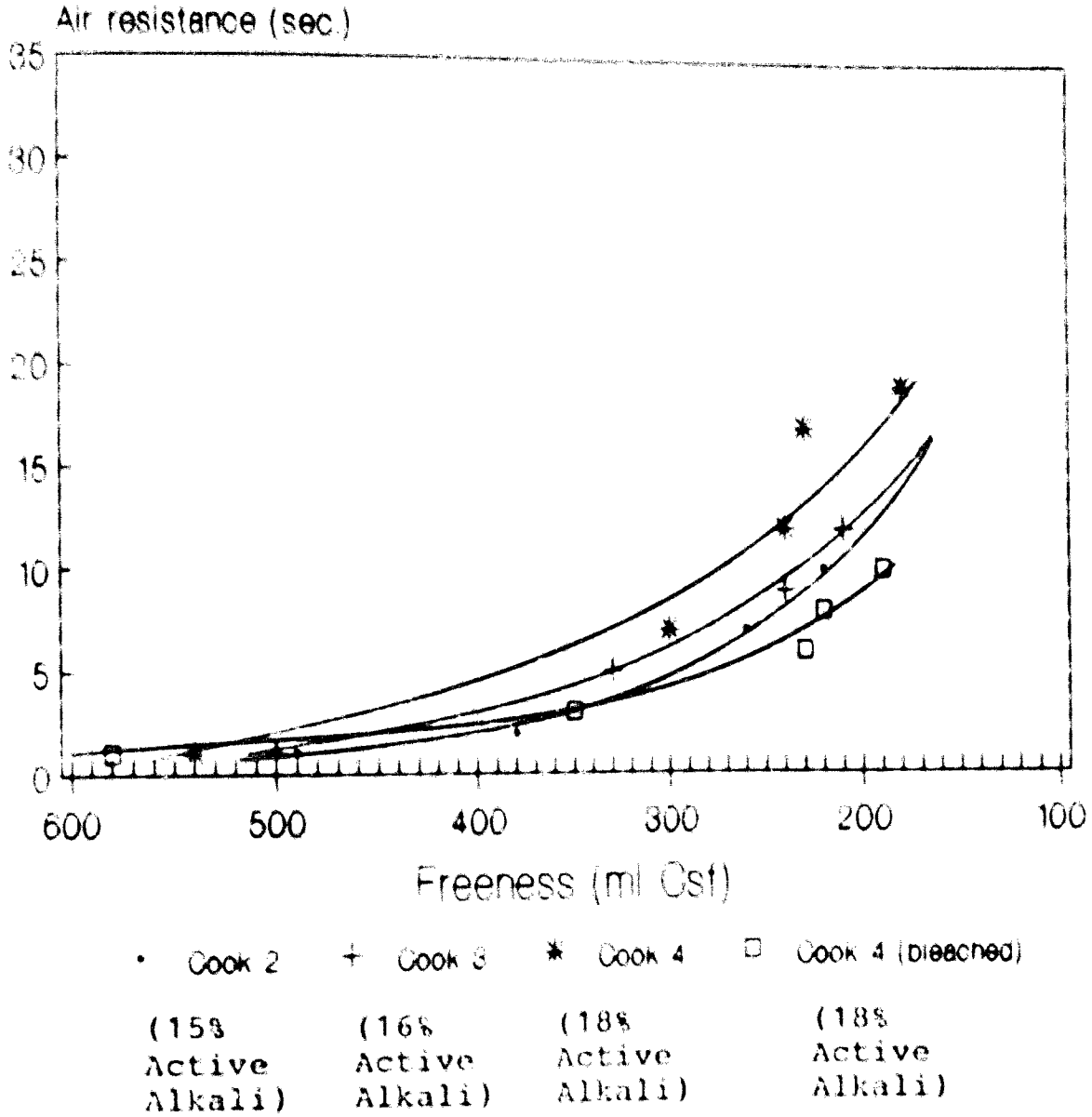


Figure 9 : Beating versus freeness of sulphate pulp from oil palm midrib

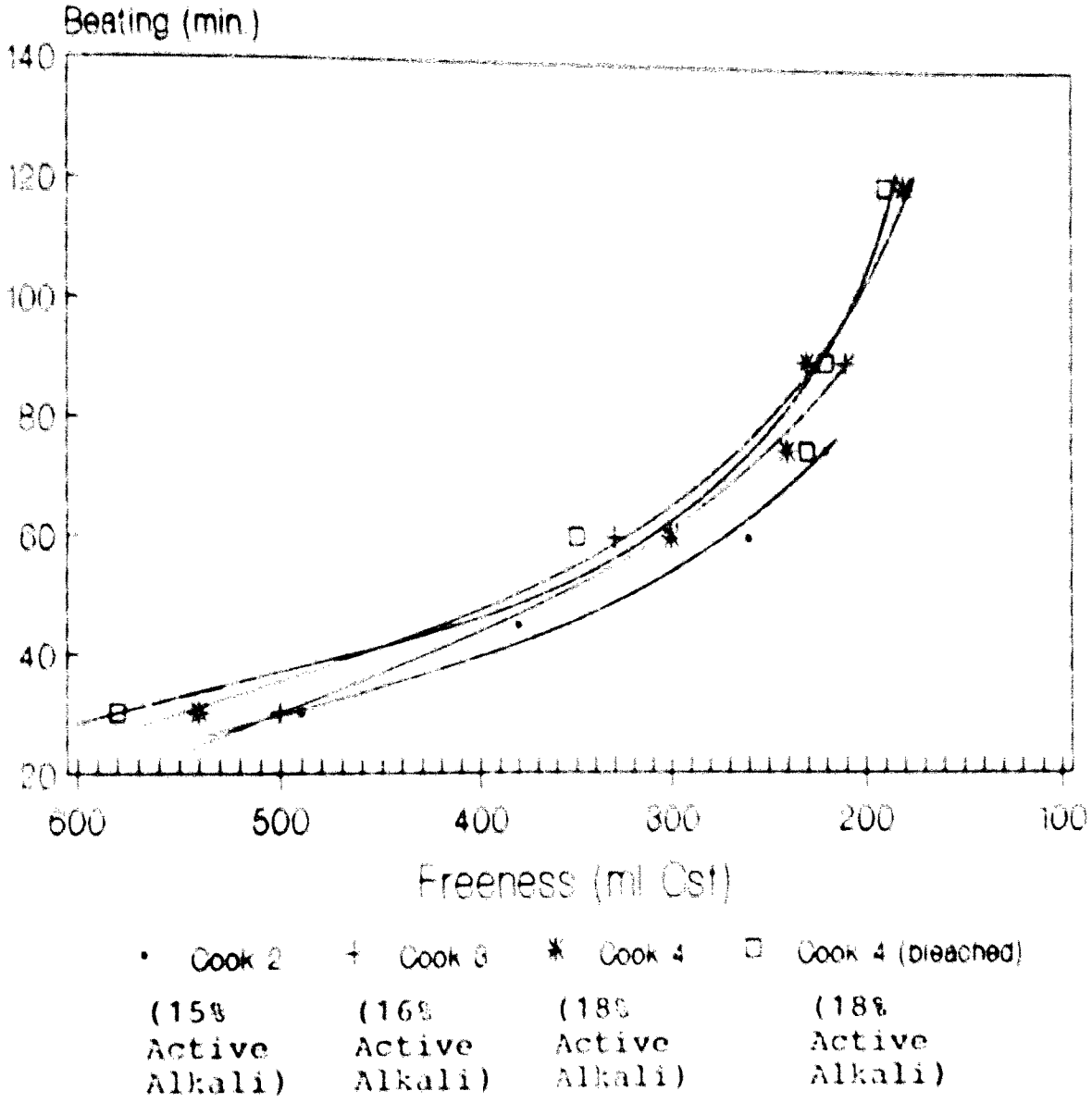
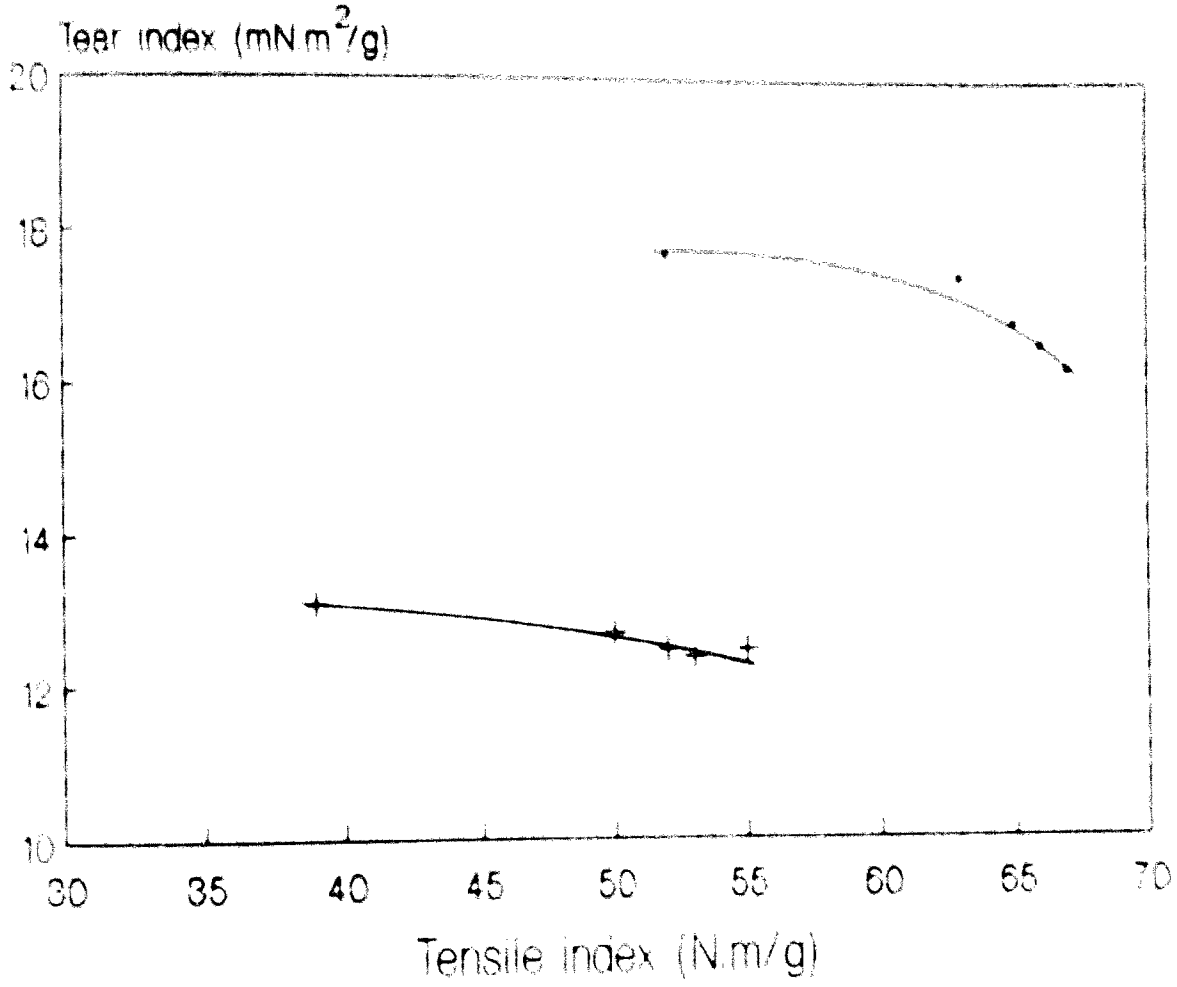


Figure 10 : Tear index versus tensile index of sulphate pulp from oil palm midrib



3.7.2 Evaluation of the physical properties of the soda pulps derived from oil palm midrib

The physical properties of the sulphate pulps of oil palm midrib were determined by the methods in Sections 2.10.1 to 2.10.6. Samples of handsheets are included in this dissertation.

Table 20 presents the results of the physical properties of the sulphate pulps of oil palm midrib.

The data in Table 20 are graphically presented in Figures 11 to 19.

Table 20: Soda pulp evaluation of the oil palm midrib

Cook No:	Beat. time (min.)	Freeness (ml Csf)	Basis wt. (g/m^2)	Thick. (µm)	Bulk (cc/g)	Air res. (sec.)	Break. length (km)	Tens. ind (N.m/g)	Stretch (%)	TEA ind. (mJ/m^2)	Tear ind. ($mN.m^2/g$)	Burst ind. ($kPa.m^2/g$)	Double folds (K x 500 g)
6	0	700	58.1	163	2.81	-	1.7	17	1.4	135	6.2	0.7	1
	15	650	58.6	133	2.26	-	3.1	30	2.6	364	8.7	1.7	5
	45	500	60.4	131	2.16	-	4.6	42	3.6	765	9.4	2.5	13
	60	300	59.7	122	2.05	1	4.7	46	4.0	954	9.5	3.1	25
	75	290	58.6	117	1.99	5	5.2	51	4.4	1111	9.7	3.6	30
7	30	560	60.2	138	2.30	-	3.6	35	2.8	514	9.9	2.1	7
	45	400	59.1	127	2.08	1	4.7	46	4.0	966	10.2	3.1	19
	60	290	58.8	118	1.99	2	5.2	51	4.7	1113	9.9	3.5	27
	75	260	59.0	114	1.94	4	5.3	52	4.7	1106	9.7	3.5	28
	90	240	60.1	111	1.85	4	5.2	52	4.7	1113	9.6	3.5	29
	120	210	58.2	106	1.82	8	5.7	56	5.1	1369	9.8	3.7	43
8	30	570	58.2	137	2.35	1	4.4	43	3.8	731	11.7	1.4	13
	60	400	58.8	107	1.82	2	5.4	53	4.5	1139	11.7	2.9	40
	90	320	58.3	102	1.75	5	6.0	61	5.1	1538	12.4	4.0	60
	120	210	58.2	101	1.74	10	6.5	64	5.5	1674	11.1	4.4	74
9	30	540	59.1	125	2.15	1	4.5	45	4.0	923	10.7	2.1	22
	60	250	58.7	105	1.81	3	5.9	57	4.9	1410	11.6	4.1	56
	75	270	58.2	101	1.80	6	5.9	56	5.1	1483	10.8	4.0	58
	90	220	58.4	91	1.95	9	5.8	56	5.5	1495	10.9	4.5	67

Figure 11 : Tear index of soda pulp from oil palm midrib at different freeness

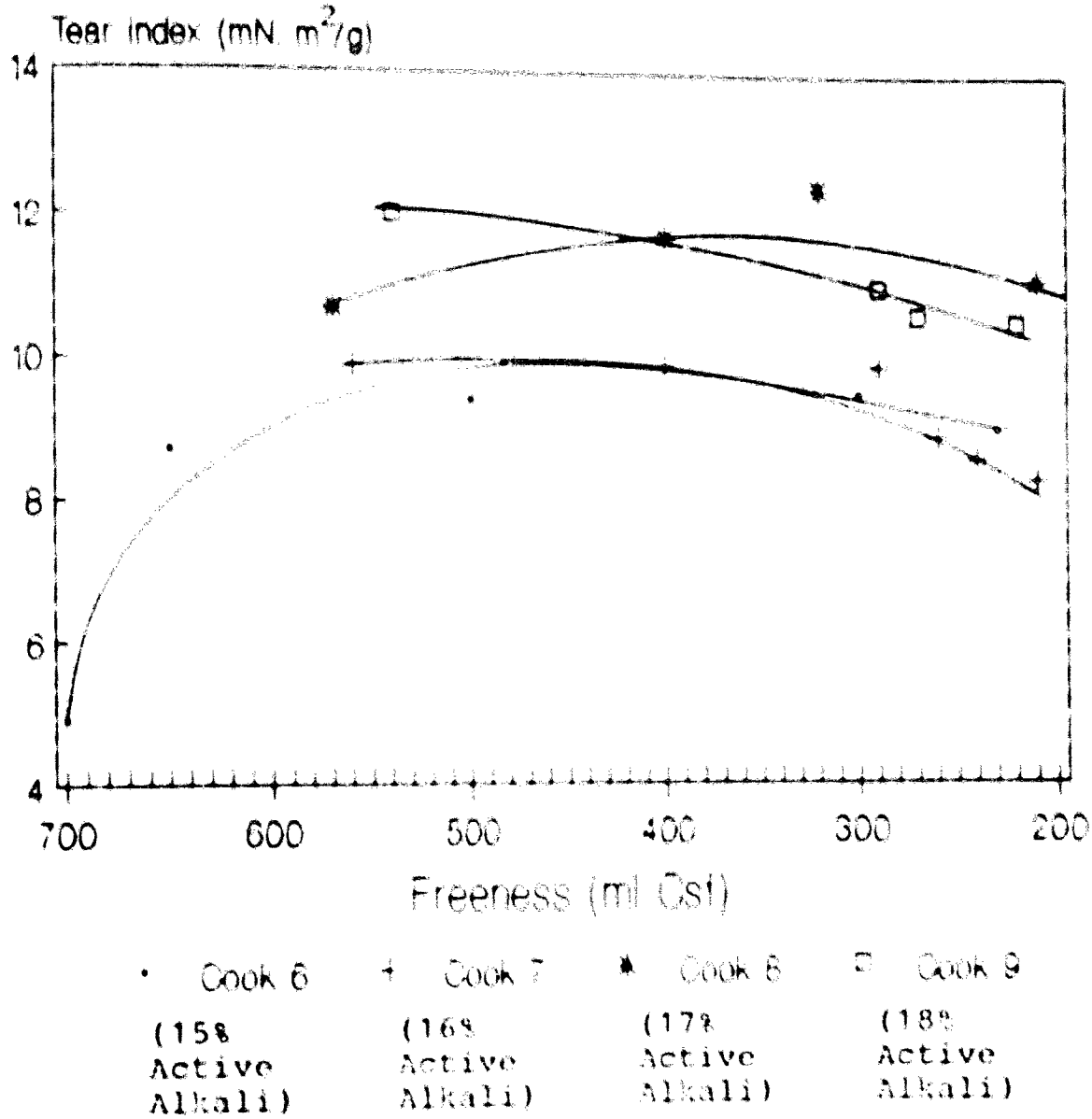


Figure 12 : Burst index of soda pulp from oil palm midrib at different freeness

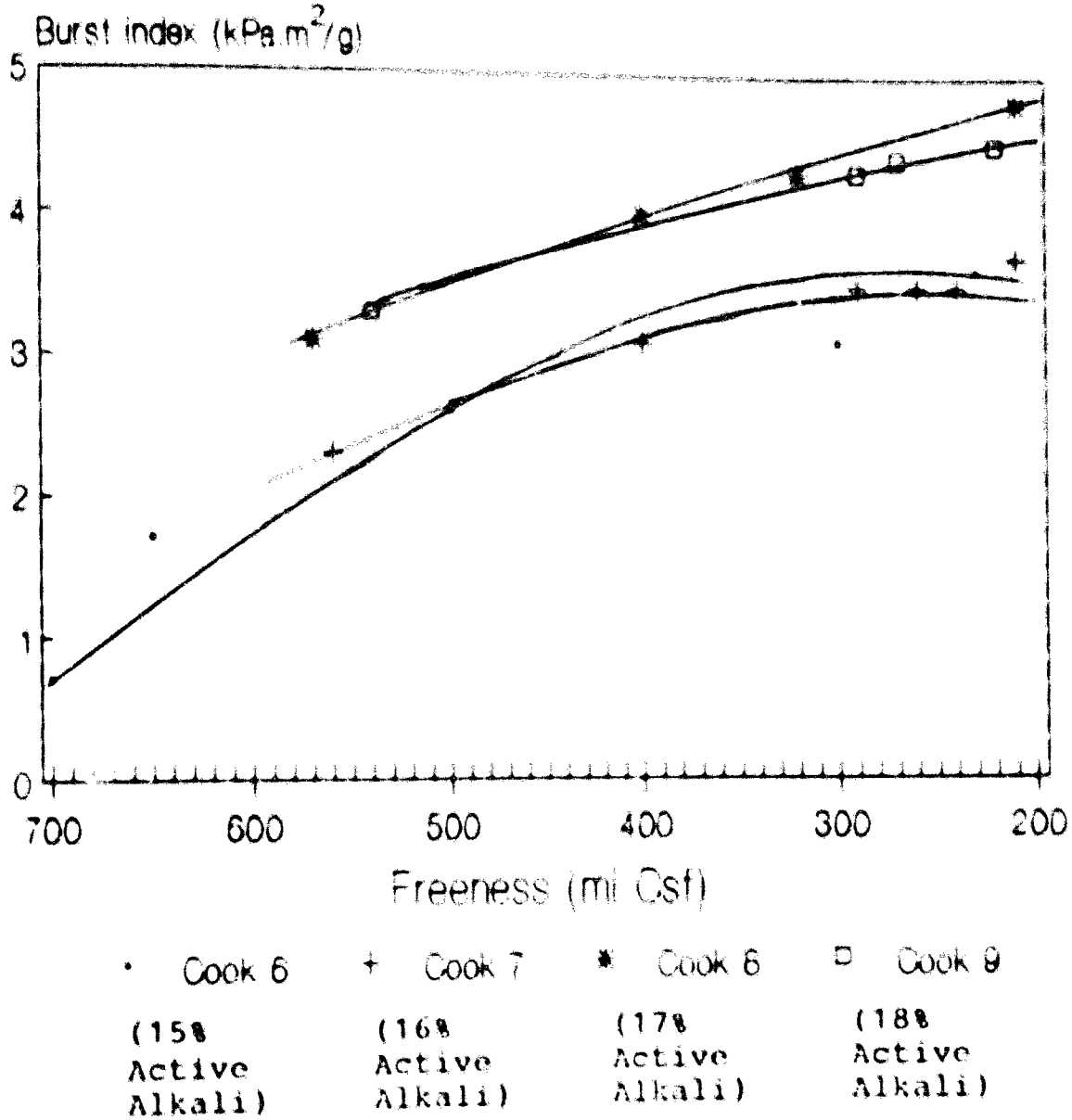


Figure 13 : Tensile index of soda pulp from oil palm midrib at different freeness

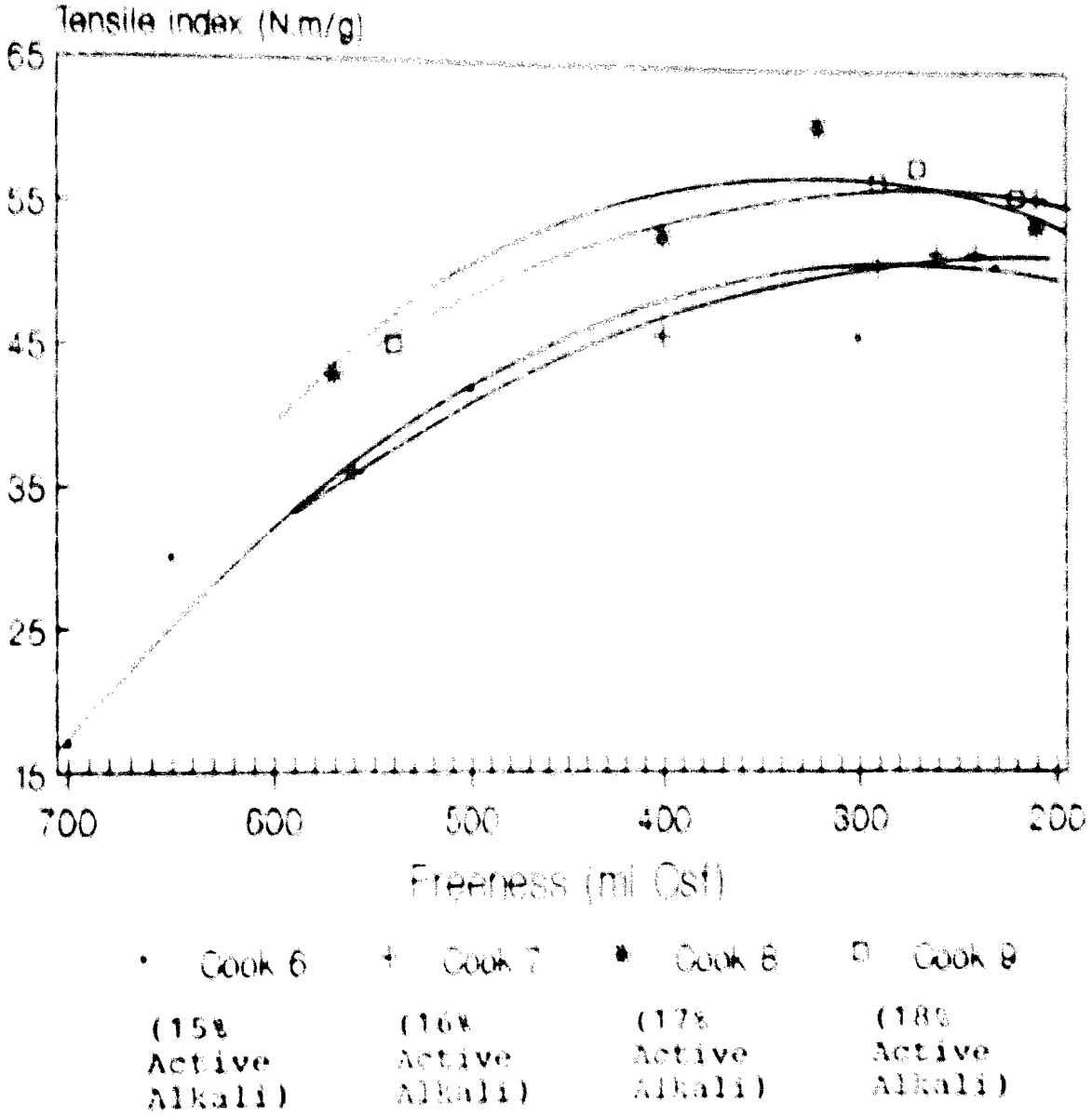


Figure 14 : TEA index of soda pulp from oil palm midrib at different freeness

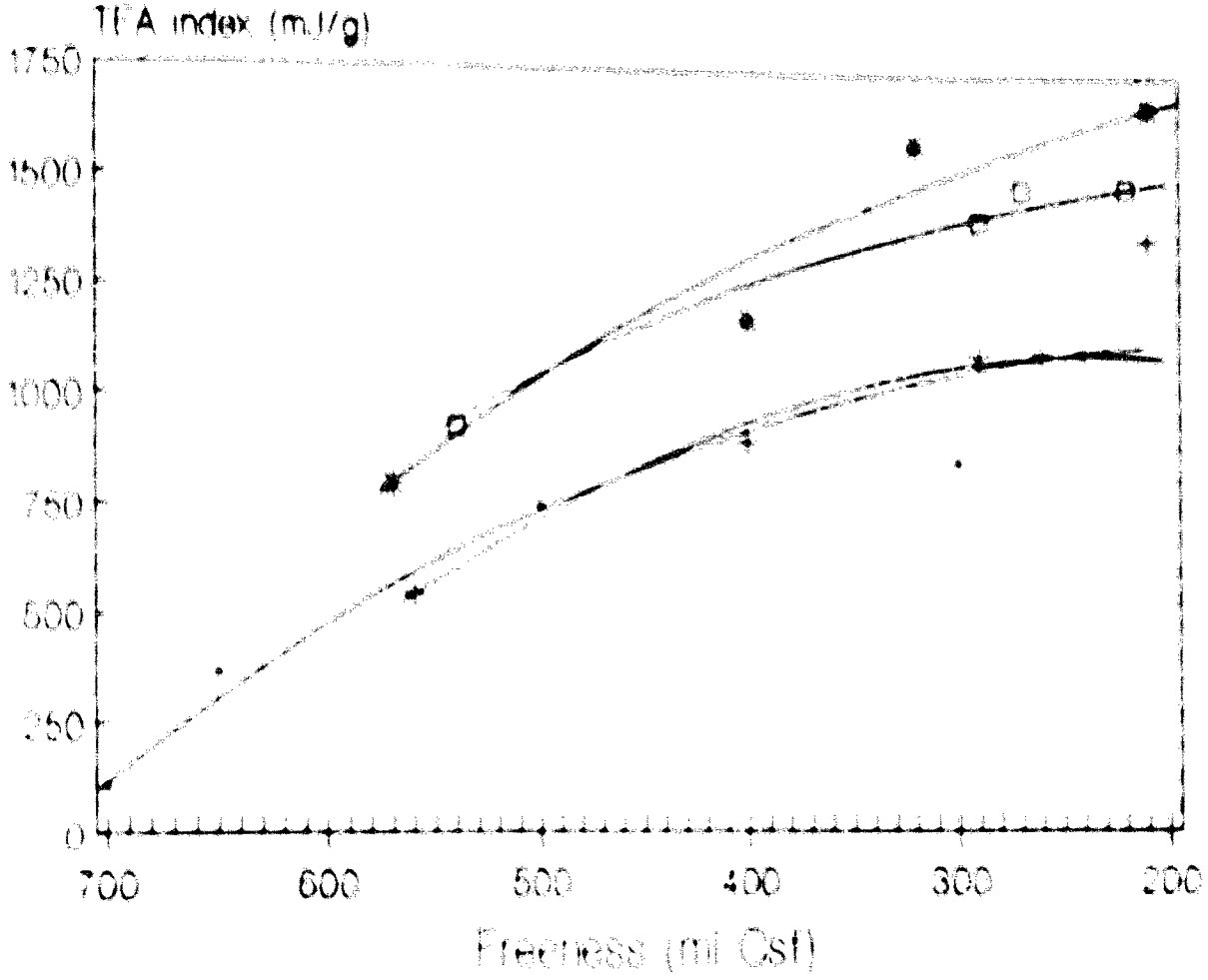


Figure 15 : Breaking length of soda pulp from oil palm midrib at different freeness

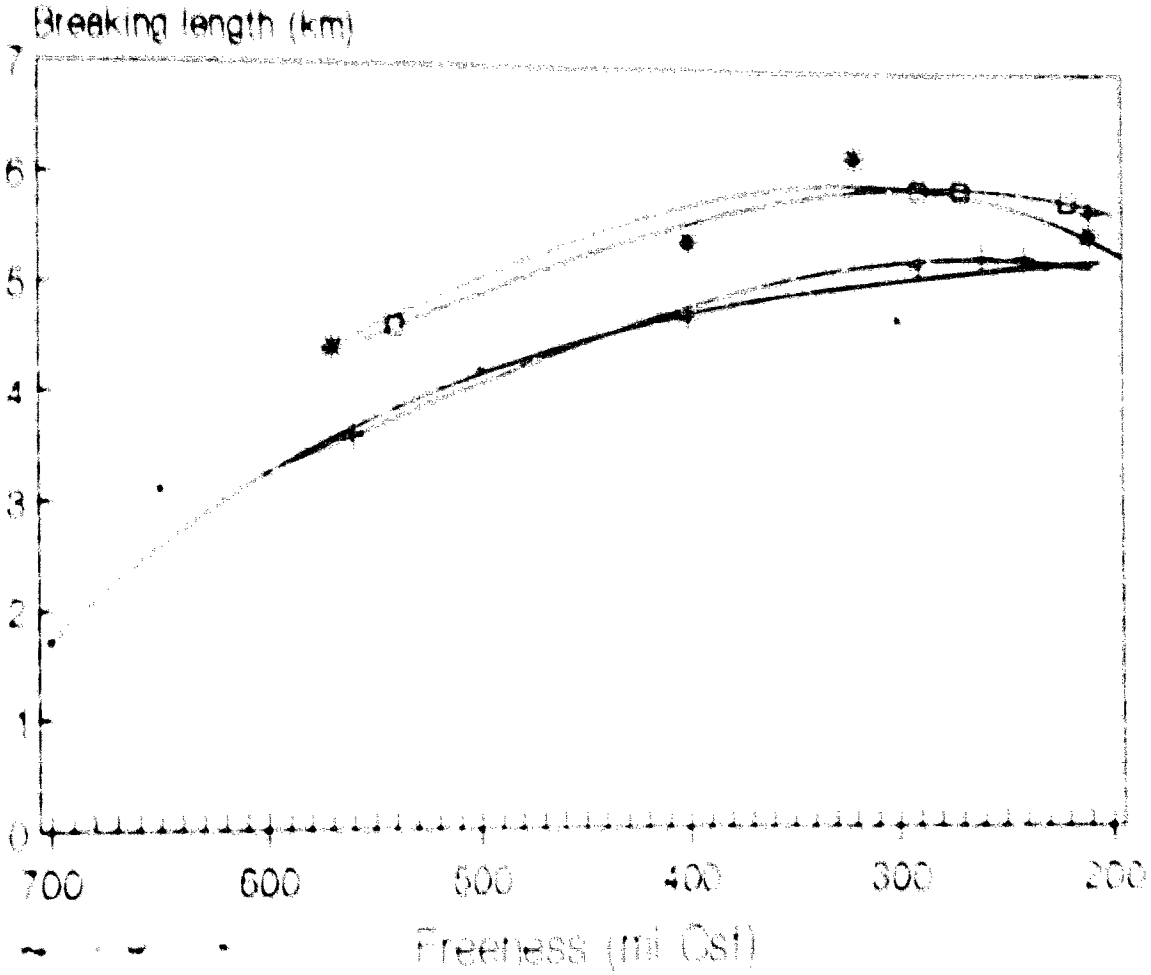


Figure 16 : Double folds of soda pulp from oil palm midrib at different freeness

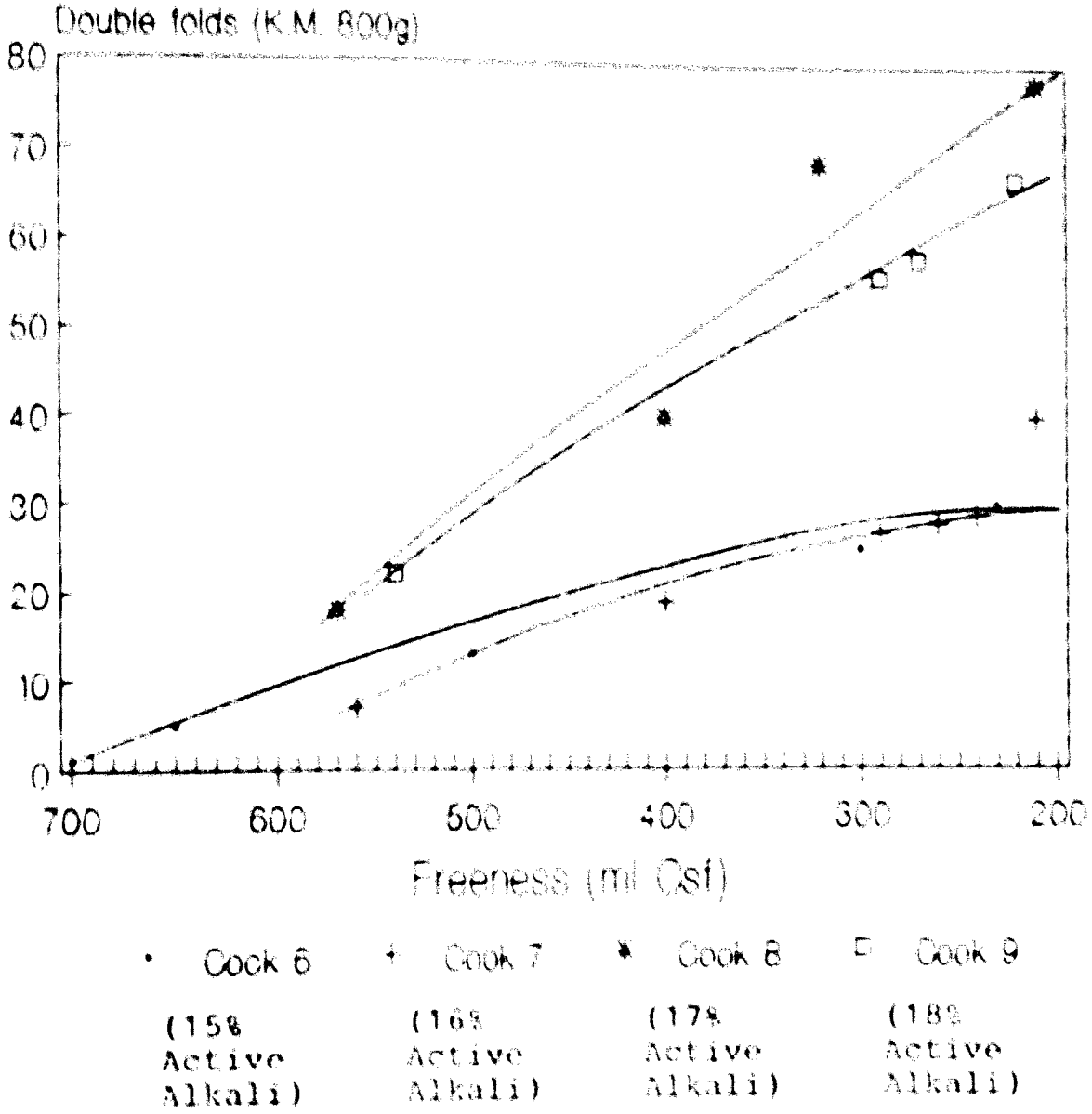


Figure 17 : Stretch of soda pulp from oil palm midrib at different freeness

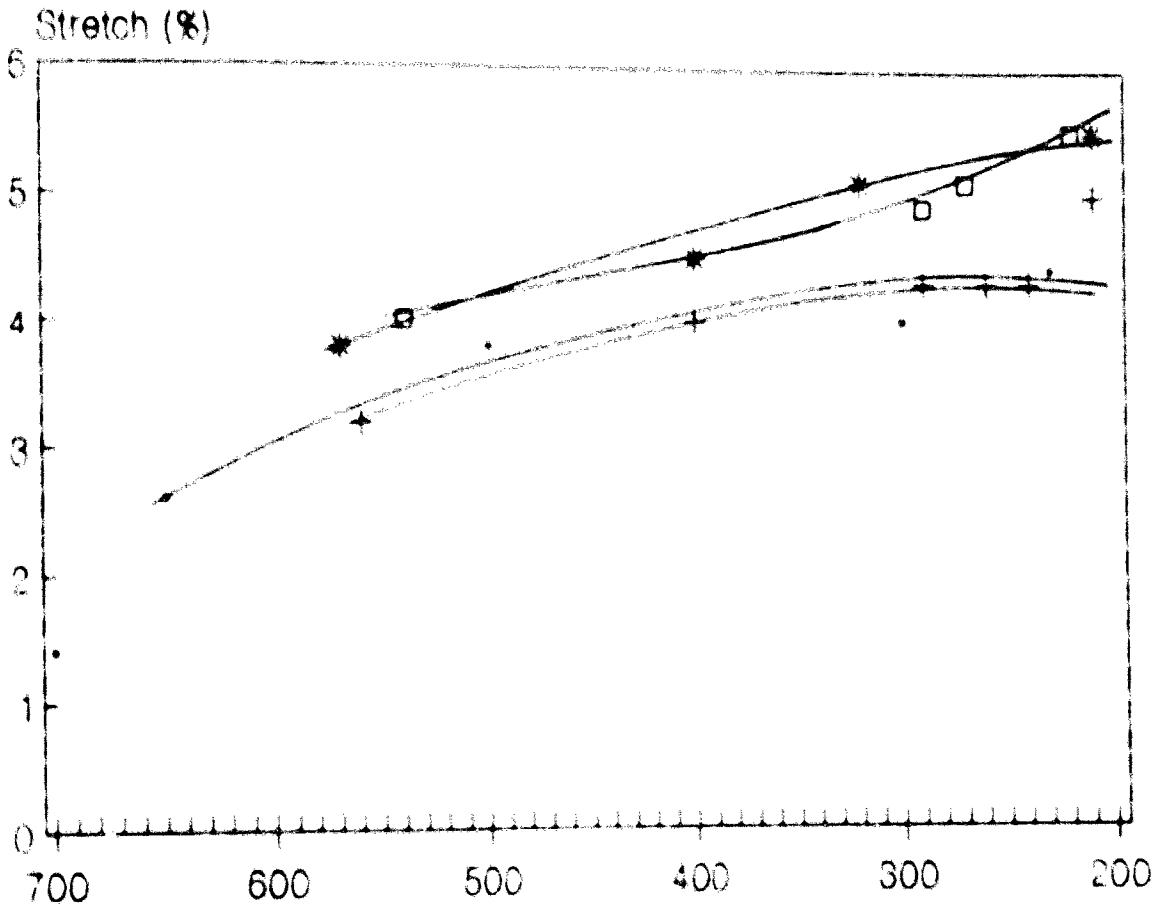


Figure 18 : Air resistance of soda pulp from oil palm midrib at different freeness

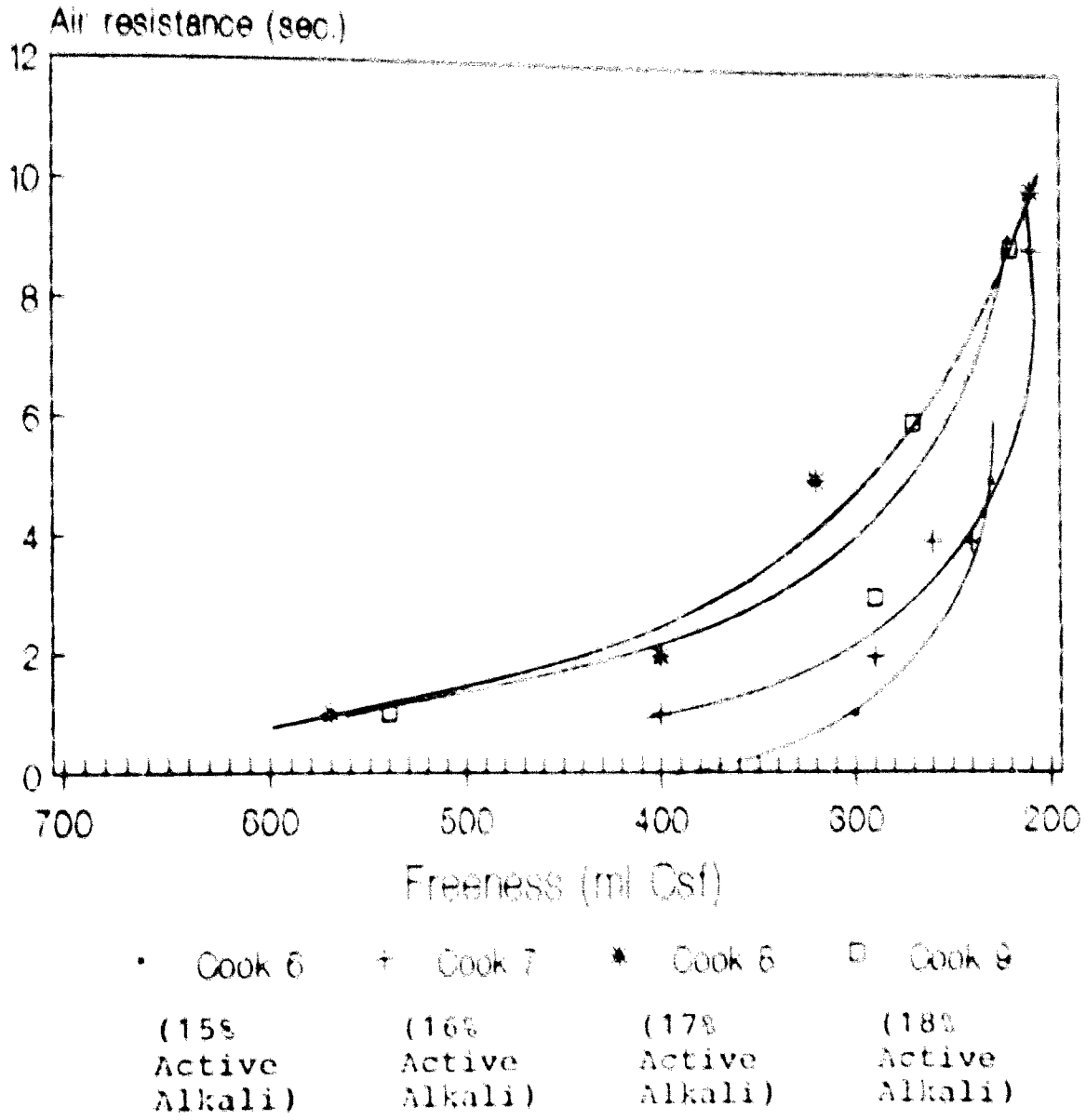
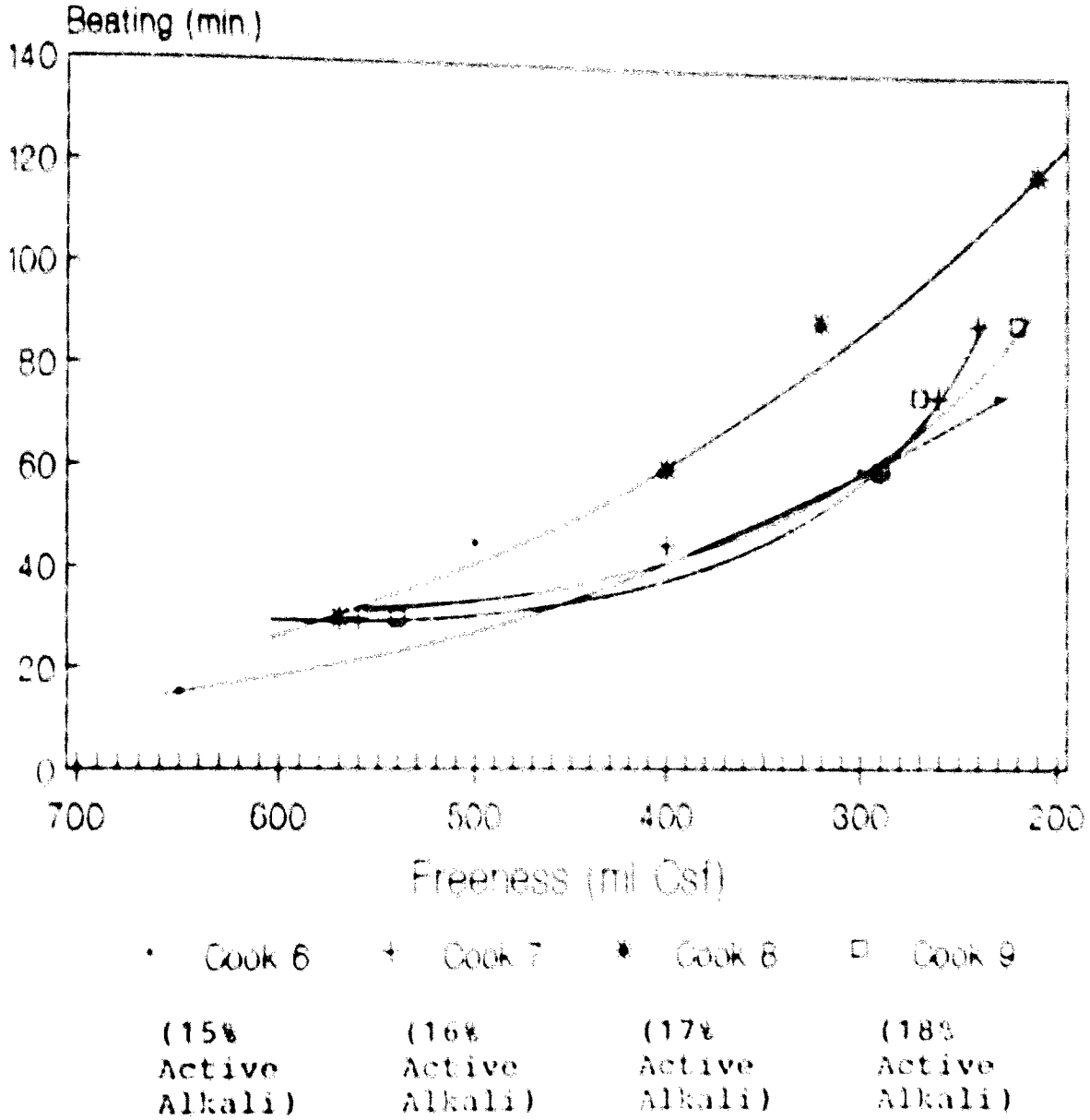


Figure 19 : Beating versus freeness of soda pulp from oil palm midrib



3.7.3 Evaluation of the physical properties of the NSSC pulps of oil palm midrib

The physical properties of the NSSC pulps were determined by the methods in Sections 2.10.1 to 2.10.6. Samples of the handsheets are included in this dissertation.

Table 21 presents the results of the physical properties of the NSSC pulps of oil palm midrib.

The data in Table 21 are graphically presented in Figures 20 to 28.

Table 21: NSSC pulp evaluation of the oil palm midrib

Cook No:	Beat. time (min.)	Freeness (ml Csf)	Basis wt. (g/m^2)	Thick. (μm)	Bulk (cc/g)	Air res. (sec.)	Break. length (km)	Tens. ind. ($N.m/g$)	Stretch (%)	TEA ind. (mJ/g)	Tear ind. ($mN.m^2/g$)	Burst ind. ($kPa.m^2/g$)	Double folds (K.M. 800 g)
10	30	440	60.4	142	2.36	1	2.3	23	1.6	183	7.2	0.5	1
	60	410	62.0	139	2.25	1	2.4	24	1.9	197	7.0	0.7	1
	90	260	60.7	130	2.13	1	2.5	25	1.8	197	9.6	0.6	1
11	30	440	60.2	138	2.29	1	2.9	29	2.2	264	4.1	1.3	2
	45	360	60.1	133	2.22	1	3.0	30	2.1	260	7.9	1.3	2
	60	350	60.3	132	2.19	1	3.4	33	2.1	291	3.6	1.1	2
	90	260	61.7	130	2.11	2	3.1	30	2.0	281	3.7	1.4	2
12	30	360	61.6	134	2.18	2	3.5	34	4.7	571	7.2	1.9	7
	45	260	59.1	131	2.16	3	4.2	42	4.8	662	5.4	2.8	10
	60	250	60.9	123	2.08	3	5.1	50	2.7	646	6.3	2.2	8
	75	220	61.4	125	2.09	5	5.2	51	2.7	646	6.1	2.3	10
13	30	390	60.6	129	2.12	1	4.7	47	2.4	547	7.1	2.4	15
	45	220	60.2	121	1.99	5	6.0	59	2.9	806	6.9	2.2	22
	60	200	61.8	119	1.95	7	6.2	61	3.0	878	6.6	3.1	34

Figure 20 : Tear Index of NSSC pulp from oil palm midrib at different freeness

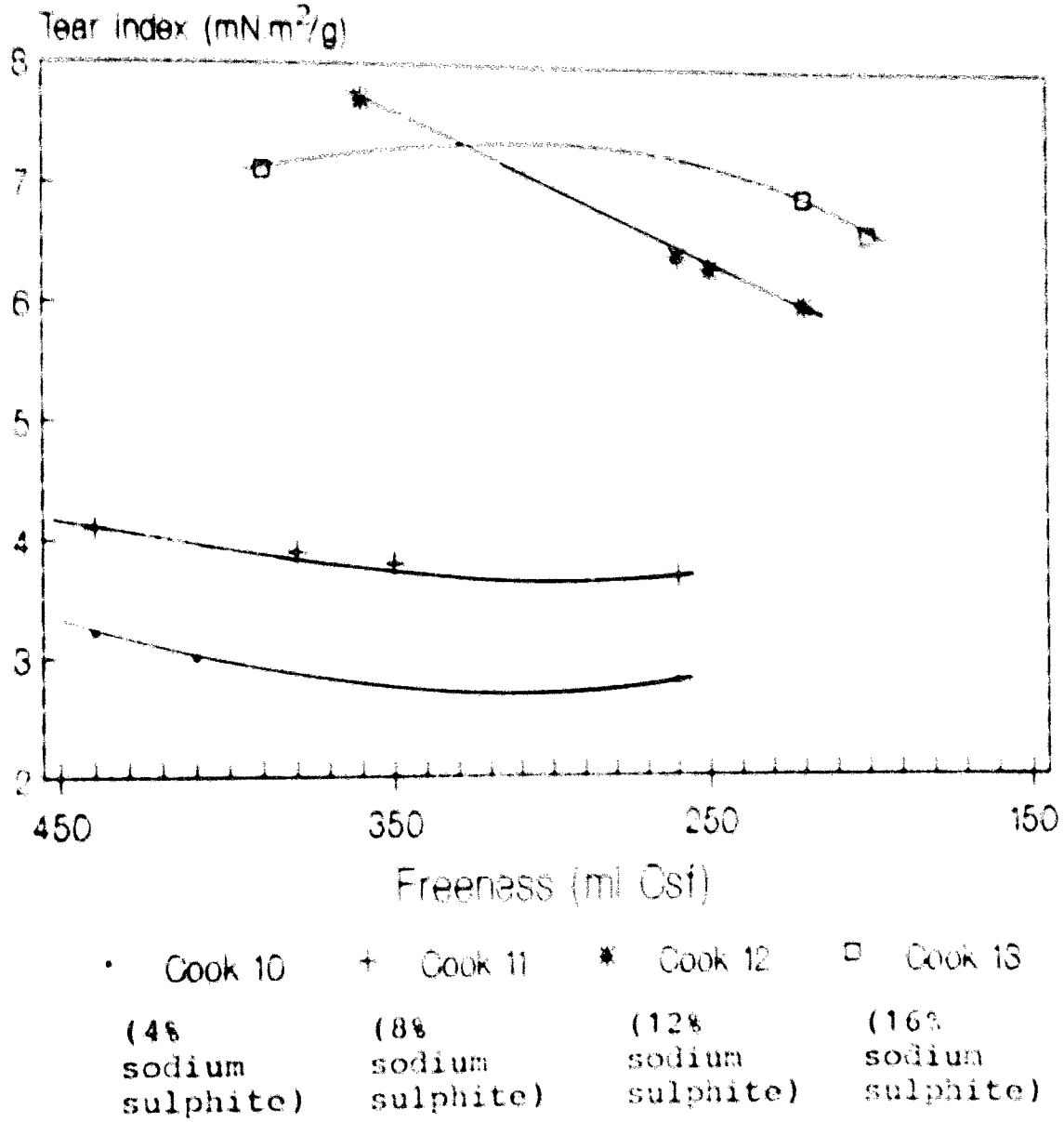


Figure 21 : Burst index of NSSC pulp from oil palm midrib at different freeness

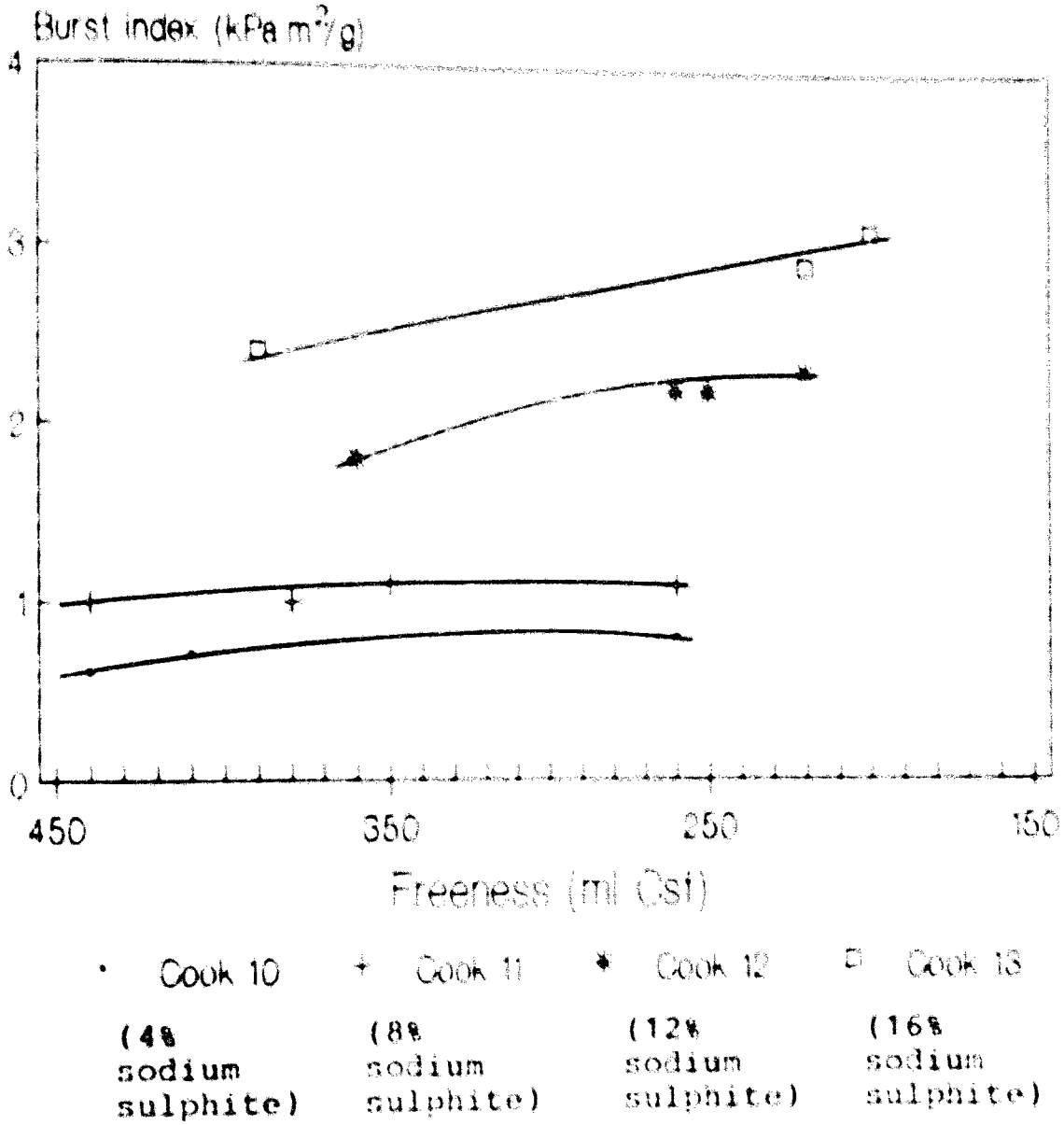


Figure 22 : Tensile index of NSSC pulp from oil palm midrib at different freeness

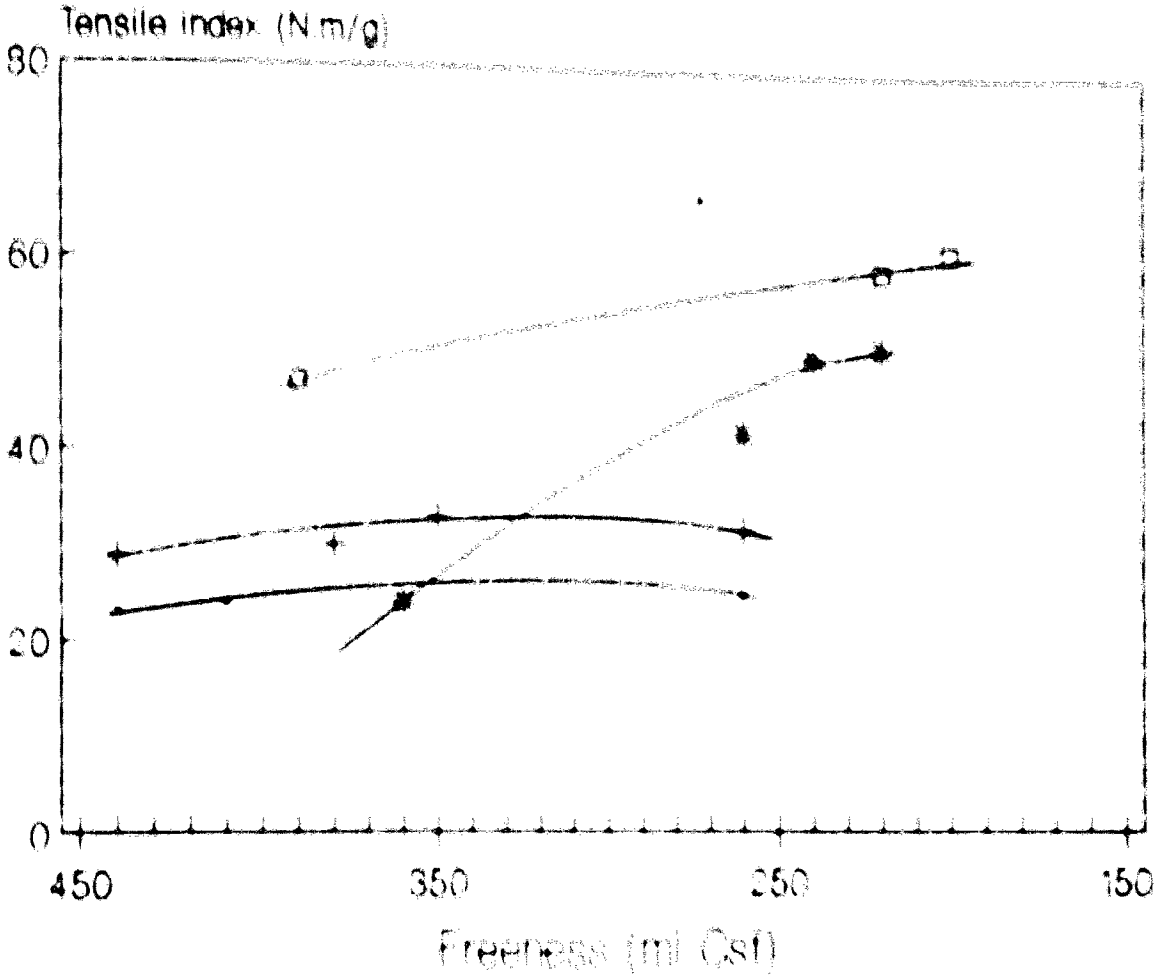


Figure 23 : Breaking length of NSSC pulp from oil palm midrib at different freeness

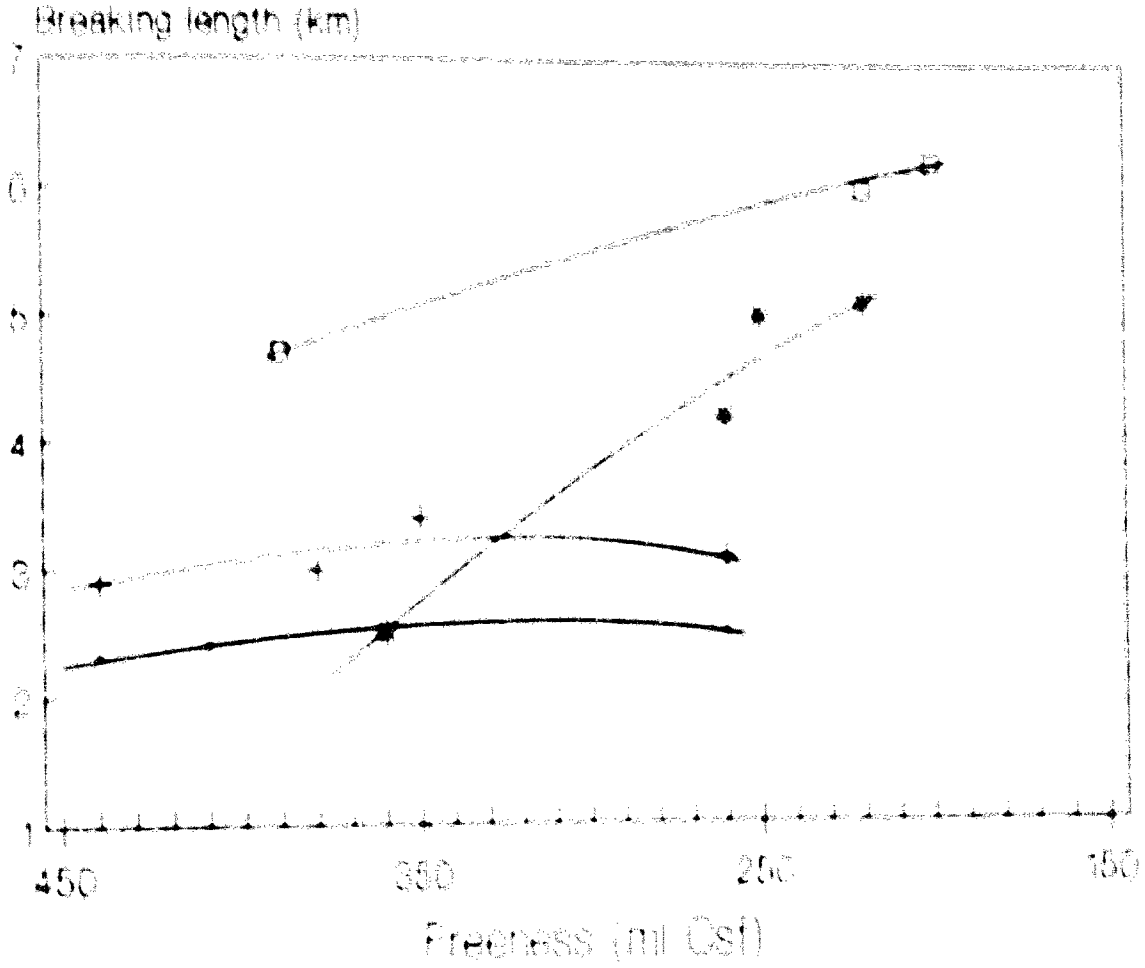


Figure 24 : Stretch of NSSC pulp from oil palm midrib at different freeness

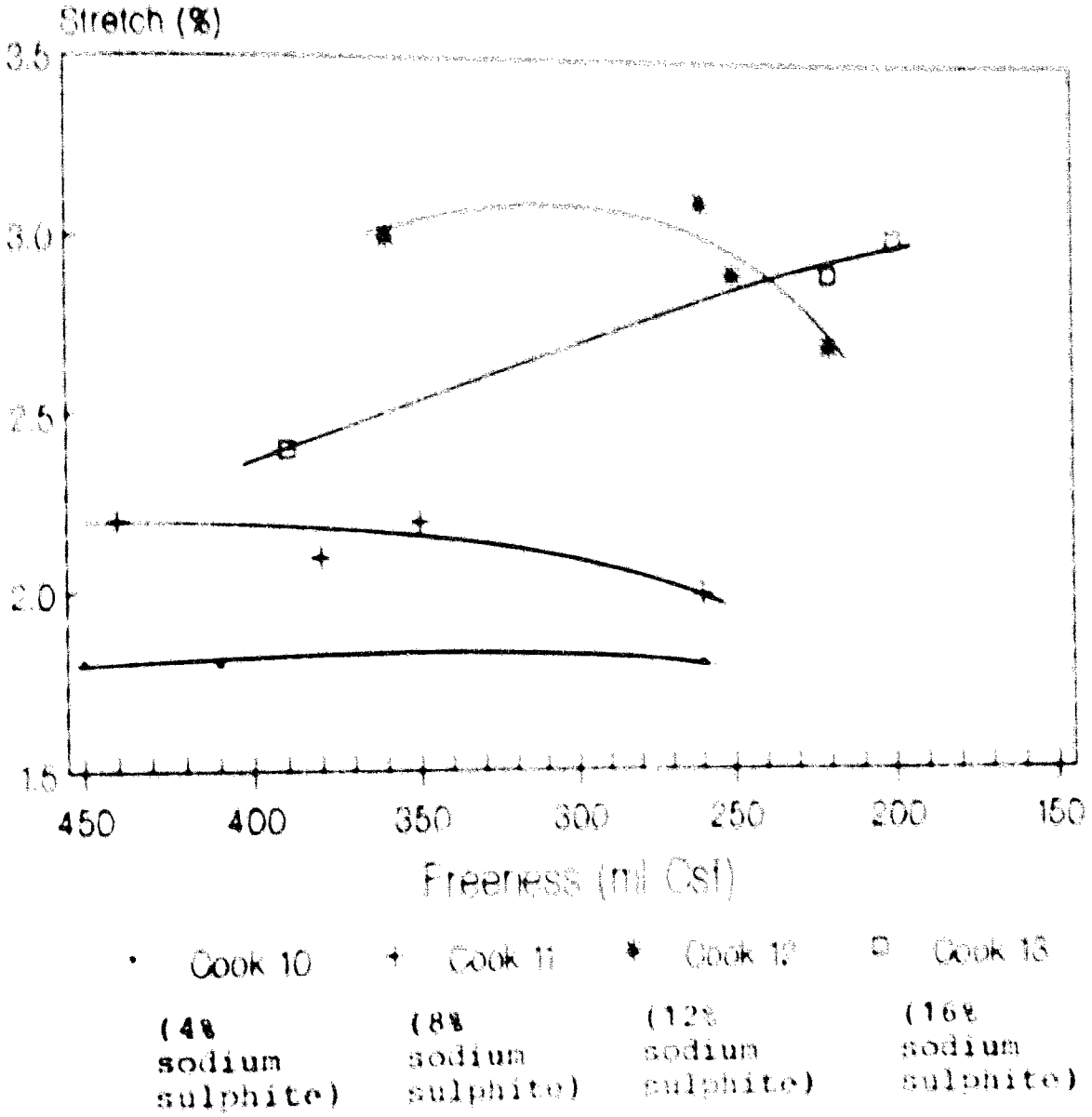


Figure 25 : TEA index of NSSC pulp from oil palm midrib at different freeness

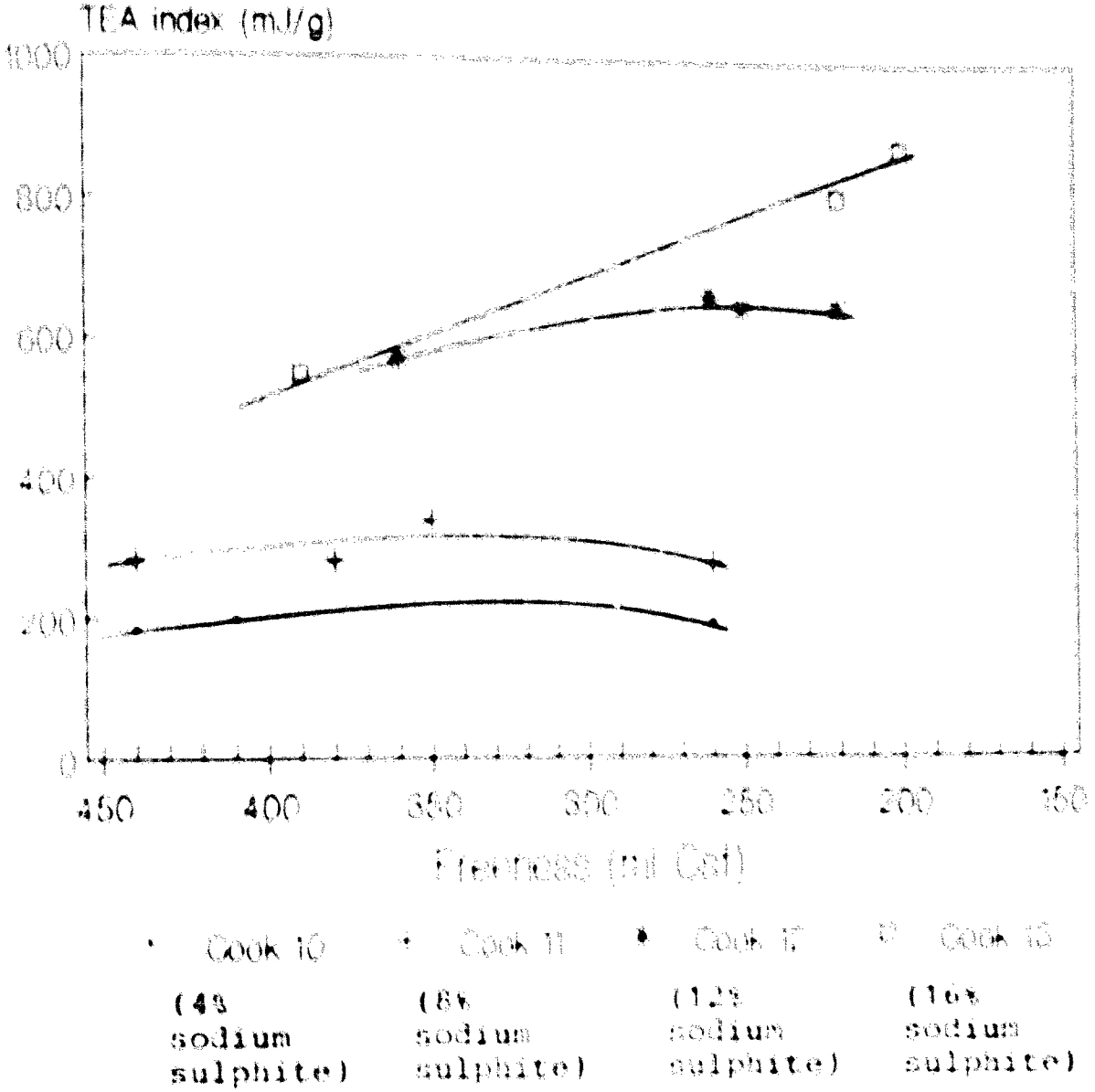


Figure 26 : Double folds of NSSC pulp from oil palm midrib at different freeness

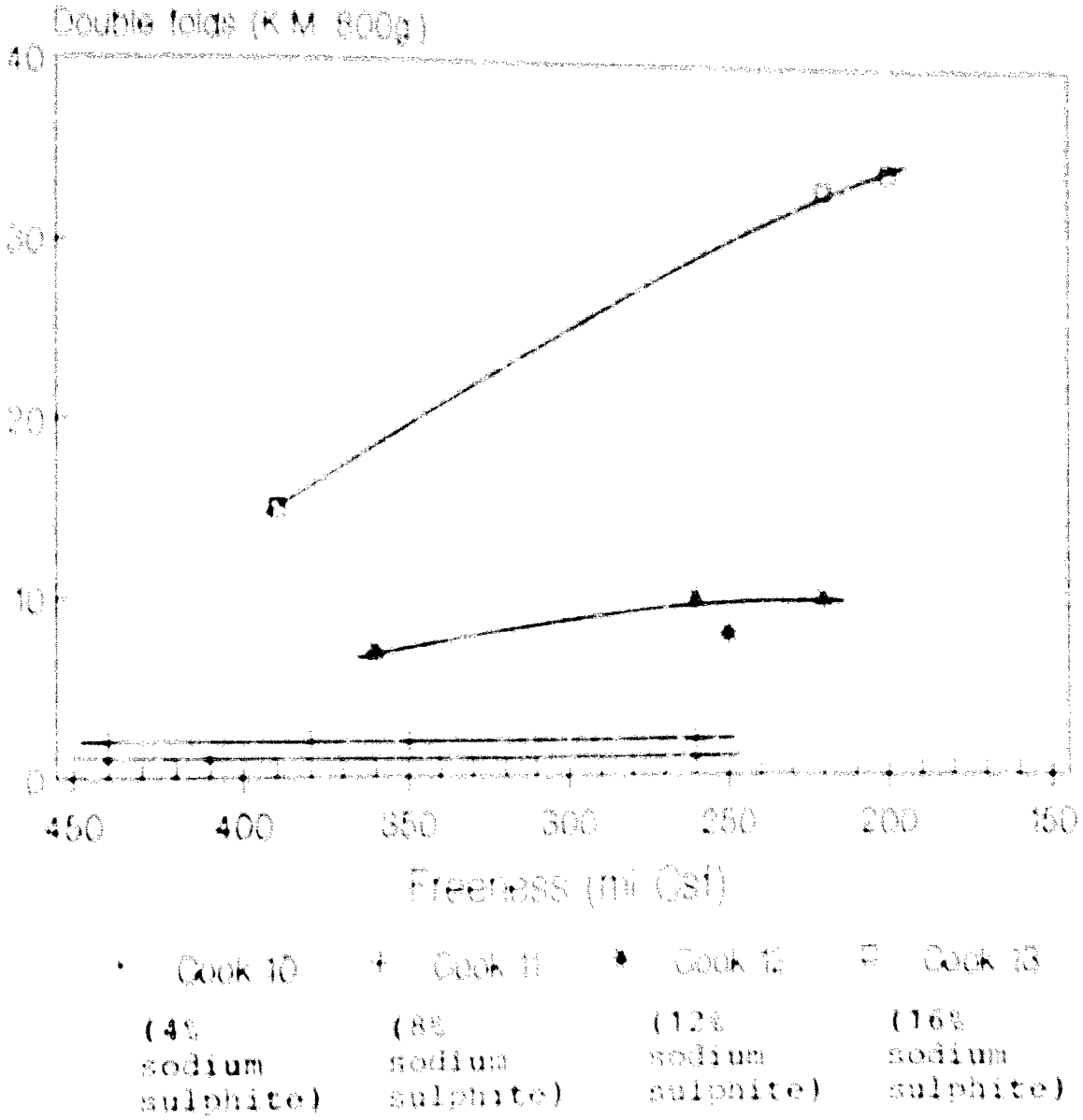


Figure 27 : Air resistance of NSSC pulp from oil palm midrib at different freeness

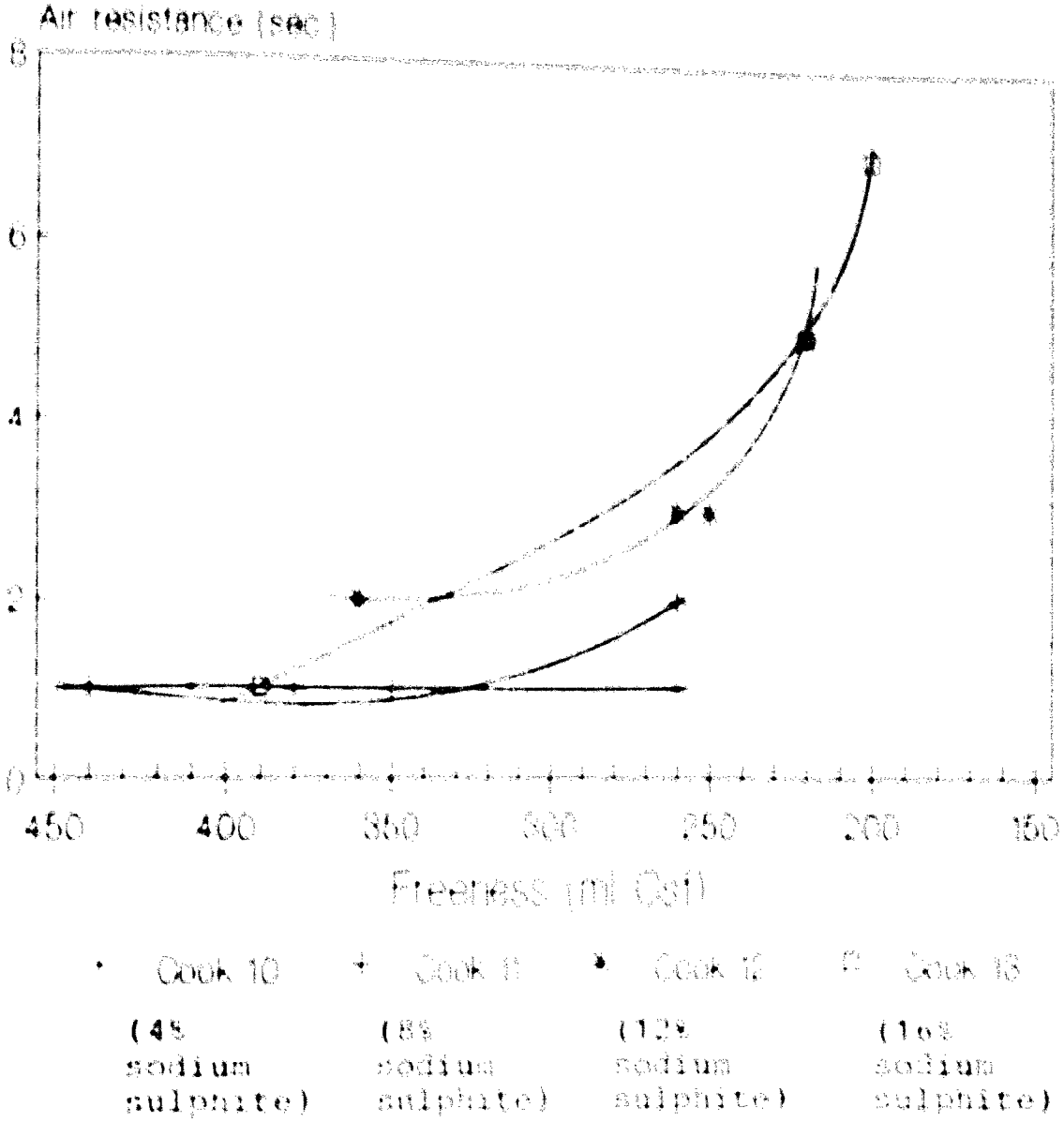


Figure 28 : Tear index versus tensile index of NSSC pulp from oil palm midrib

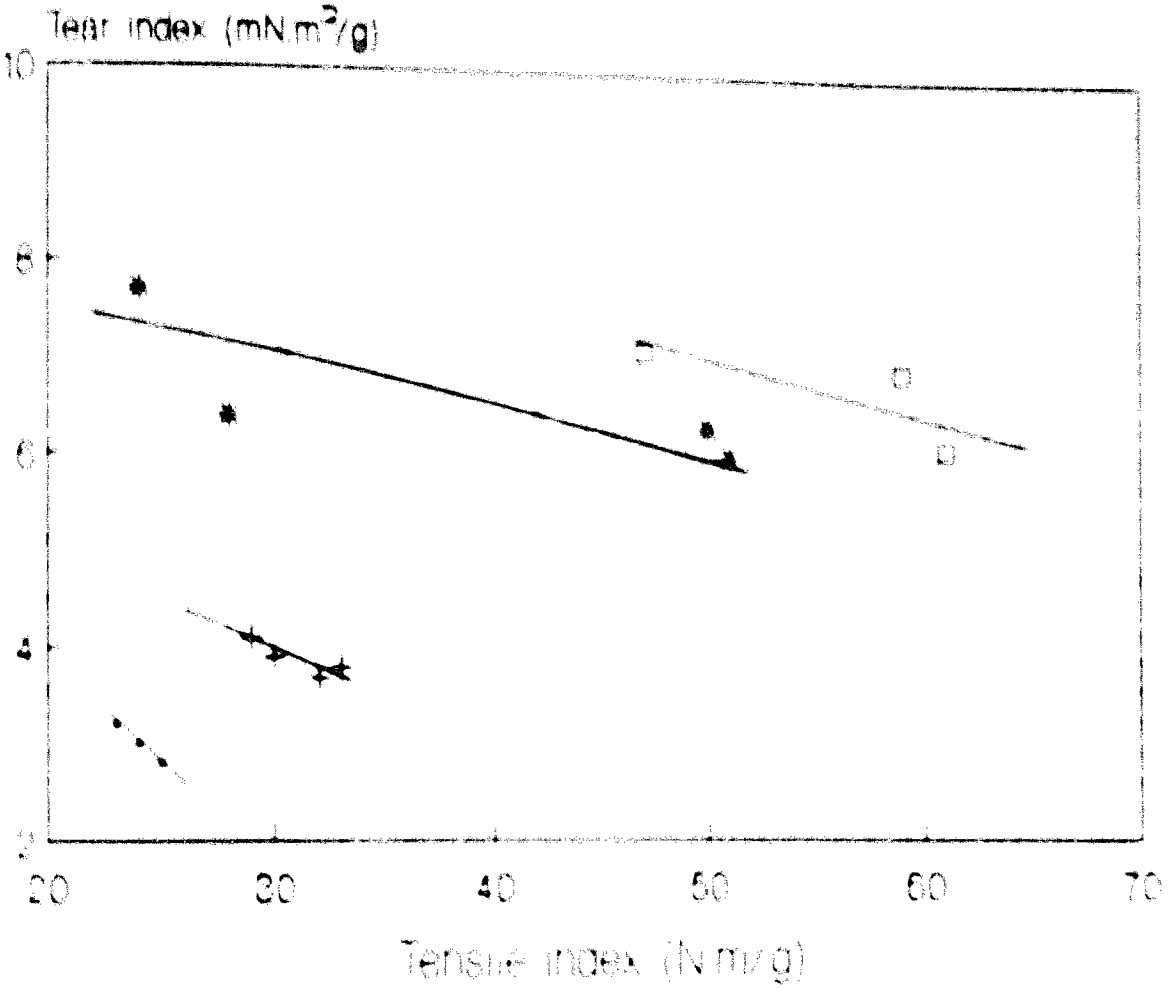


Figure 29 : Yield of NSSC pulp from oil palm midrib