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PROPERTIES OF SULPHATE- AND SODA-ANTHRAQUINONE PULPS FROM OIL PALM TRUNK

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MOHD NOR MOHD YUSOFF, KHOO,K.C. & LEE,T.W. 1989. Properties of sulphate- and soda-anthraquinone pulps from oil palm trunk. Fibrous strands from the oil palm trunk were pulped by the sulphate and soda processes with and without anthraquinone. The addition of only 0.1% anthraquinone in both sulphate and soda pulping gave rise to higher yield and lower kappa number, especially at 11 and 13% active alkali for the sulphate cooks and 18% for the soda cooks. However, all the anthraquinone cooks, whether bleached or unbleached, did not show any marked general improvement in strength properties over the normal cooks except for the bursting strength in the soda anthraquinone cook.

Key words: Oil palm trunk - sulphate - soda - anthraquinone pulp

Introduction

Non-wood raw materials, especially wheat and rice straw, bamboo and bagasse are important sources for papermaking in developing countries. In Malaysia, another source of non-wood fibrous raw material comes from oil palm wastes in the form of trunks, fronds and empty fruit bunches. In Peninsular Malaysia, annually, a large hectarage of oil palm is replanted, generating a considerable amount of waste. This waste represents a potentially useful lignocellulosic raw material for conversion into pulp and paper. Sulphate pulping of fibrous strands could be achieved at 14% active alkali to give pulps of moderate yield and strengths and neutral sulphite semichemical pulps of acceptable strength properties were obtained at low chemical charge from 4 to 10% sodium sulphite and short digestion time (Khoo & Lee 1985). An acceptable pH condition was achieved with addition of 8% sodium carbonate (Mohd. Nor 1985).

Since the 1970s, several studies have been conducted on the influence of anthraquinone or quinone additives in conventional pulping processes. These studies indicate that the incorporation of just a small amount of the chemical additives is sufficient to accelerate the process of delignification with little or no detriment to the cellulose. Ghosh *et al.* (1977) obtained such modified soda pulps (with quinone additives equivalent to 0.05% of anthraquinone on wood addition) which produced lower rejects and had comparable or higher strength properties than conventional bleachable-grade kraft or soda pulps. Laboratory, pilot plant and full mill kraft pulping of southern pine using 0.05% anthraquinone produced a reduction in cooking time and alkali consumption while producing equivalent pulp of the same κ number without anthraquinone (Holton & Chapman 1977). With 0.022% on wood of 1,4-dihydro-9,10-dihydroxy anthracene (DDA), a quinone additive in place of anthraquinone, in the kraft pulping of eucalyptus, a 9% increase in production without a rise in pulping temperature or increase in chemical charge was obtained (Furuya 1984).

In the present study, we investigated the response of oil palm trunk to sulphate- and soda-anthraquinone (AQ) pulping so as to optimise its usefulness as a pulping material.

Materials and methods

Thirty-year-old oil palm trunks (OPT) from a Batang Berjuntai plantation, Peninsular Malaysia, were prepared by manual and mechanical processing to separate the fibrous strands from the parenchyma cells which constitute the non-fibrous material. The fibrous strands were washed clean, dried and stored in plastic bags to be used when required.

In the pulping trials (Table 1) each charge of 400 *g* fibrous strands (optimum density) was cooked in a MK Digester. Sulphate and soda pulping with and without anthraquinone were conducted to determine the effects of anthraquinone addition. The sulphate pulping conditions were as follows: sulphidity 25%; liquor to wood ratio 5:1; maximum temperature at 170°C; 1.5 *h* to maximum temperature and 2.0 *h* at maximum temperature. The active alkali was varied from 11.0 to 14.0%.

Table 1. Pulping conditions of oil palm trunk

Type of cook	Active alkali (as Na_2O, %)	κ number	Pulp yield (%)		
			Screened	Screening	Total
Sulphate	11	44.0	45.7	10.1	55.8
Sulphate - AQ	11	40.6	51.3	3.3	54.6
Sulphate	13	38.6	49.8	2.8	52.6
Sulphate - AQ	13	28.3	52.6	1.8	54.4
Sulphate	14	21.4	49.5	0.9	50.4
Sulphate - AQ	14	20.0	50.8	0.8	51.6
Soda	18*	28.0	49.8	2.2	52.0
Soda - AQ	18*	15.2	52.0	0.9	52.9

* Based on oven dry weight of strands

The amount of anthraquinone added into the liquor was fixed at 0.1% based on oven dry weight of raw material. This amount is a value beyond which the use of anthraquinone in pulping would not be economical and represents the upper limit permitted by the Food and Drug Authority (FDA) of the United States (Eckert *et al.* 1984). After digestion, the pulp was washed thoroughly with water, disintegrated in a hydrapulper and screened in a fractionator. Kappa number of the screened pulp was determined according to TAPPI T236. Beating of pulp was carried out in a Lampen mill according to APPITA P202-75. Forming handsheets and testing them after conditioning at 20°*C* and 65% R.H. were carried out according to APPITA P203-75 and APPITA P208-75, respectively.

The screened sulphate pulp which had a j number around 20 was used in the bleaching study. To achieve acceptable brightness and brightness stability, the multistage Chlorination - Alkali Extraction - Chlorine Dioxide - Alkali Extraction - Chlorine Dioxide (CEDED) sequence was adopted. The bleaching conditions employed are given in Table 2. The brightness and colour reversion of the bleached pulps were determined according to ISO 2740 and TAPPI UM 26, respectively.

Table 2. Pulping conditions of oil palm trunk

Treatment	Pulp consistency (%)	Temperature (°*C*)	Reaction time (*h*)	Chemicals (%)
First stage (Cl_2)	4	25	1	120* (ρ number)
Second stage (NaOH)	6	60	1	2.5
Third stage (ClO_2)	10	60	2	1.0
Fourth stage (NaOH)	6	60	1	1.5
Fifth stage (ClO_2)	10	60	2	1.0

* ρ number = κ number × 0.16

Results and discussion

For the purpose of pulping, the non-fibrous components in the trunk have to be separated from the fibrous strands because, in general, it does not contribute to paper strength and decreases drastically the drainage of the pulp during papermaking. In addition, it consumes a large amount of chemicals during pulping and bleaching. The strands were not difficult to pulp but had to be packed tightly into the vessel to attain the required load and to achieve good circulation of the cooking liquor.

The results of the alkaline pulping with and without anthraquinone of the fibrous strands are given in Table 1. The active alkali of the sulphate cook was varied from 11 to 14% in order to obtain a j number ranging from 44 to 20. It is interesting to note a general trend here in which sulphate pulping with anthraquinone showed an increase in screened pulp yield and a drop in κ number over sulphate pulping without anthraquinone. With anthraquinone the shive content at the same time decreased. The soda cooks showed the same significant effect by anthraquinone in increasing the pulp yield and decreasing the κ number. Farrington *et al.* (1977) had observed the effect of small quantities of AQ on soda cooking of eucalypt whereby a higher pulp yield at lower κ number was obtained as compared with soda cooking. The significant effect of AQ addition during alkaline pulping had been explained in terms of it being a delignification agent, catalyst and carbohydrate stabiliser and becoming chemically combined with lignin and carbohydrate in the early stages of soda pulping (Anonymous 1981). The addition of small amounts of AQ to alkaline pulping which increases the rate of delignification has also been observed by Fullerton (1978) and Ingruber (1985).

The properties of sulphate and soda pulps are given in Table 3. Most of the results given are on unbleached pulps. In Figure 1, the unbleached sulphate-AQ pulps showed slightly lower strength properties than the normal sulphate pulps. The unbleached soda-AQ pulps showed slightly higher burst but lower tensile strength than the normal soda pulps. At freeness less than 450 *ml* csf, both soda pulps showed no marked difference in tear. The effectiveness of AQ in soda pulping was reported by Farrington *et al.* (1977) in which pulps with strength properties similar to those kraft pulps were produced at the same or at slightly higher yields. However, Farrington *et al.* (1979) showed that the mill soda-AQ and kraft pulps had identical tear indexes but that burst index of the soda-AQ pulp was *circa* 6 to 7% lower. In Figure 2, plots of tear index against tensile index showed that the tear index at a given tensile index was generally slightly lower for sulphate anthraquinone pulps than the normal sulphate pulps (except at tensile index greater than 95 $Nm\ g^1$ where the tensile index was similar in both pulps). For soda-AQ pulps, the tear index was lower only at a tensile index greater than 70 $Nm\ g^1$.

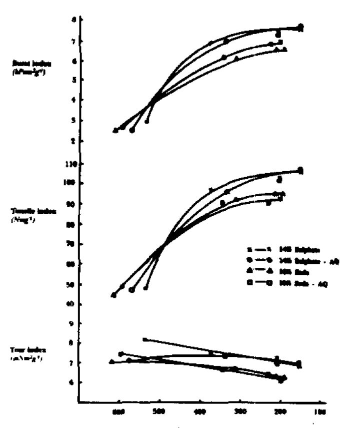

Figure 1. Strength properties of unbleached sulphate and soda pulps from oil palm trunk

Table 3. Properties of sulphate and soda pulps

Sample	Beating time (*min*)	Freeness (csf, *ml*)	Bulk ($cm^3 g^{-1}$)	Tensile index ($Nm g^{-1}$)	Stretch (%)	TEA index ($mJ g^{-1}$)	Tear index ($m Nm^2 g^{-1}$)	Burst index ($kPa m^2 g^{-1}$)	Double folds (K. M. 800 *g*)	Air resist (*s*)
11% sulphate	0	590	1.94	43	2.7	620	7.5	2.5	32	2.1
	30	345	1.61	88	4.4	2070	7.1	6.2	957	12
	60	220	1.52	93	4.6	2320	6.8	6.9	508	181
	90	180	1.46	93	4.5	2290	7.0	7.1	1689	346
11% sulphate-AQ	0	600	1.90	43	2.6	590	7.4	2.4	24	1.9
	30	340	1.55	89	4.4	2060	7.1	6.2	1165	63
	60	230	1.50	93	4.4	2180	7.3	6.5	1412	190
	90	165	1.47	95	4.5	2110	6.9	7.0	1809	436
13% sulphate	0	675	1.73	51	3.2	850	7.3	3.2	80	4.8
	30	520	1.45	95	4.7	2320	6.8	6.7	1193	88
	60	390	1.45	104	5.0	2590	6.7	7.2	1833	204
	90	275	1.36	106	5.1	2760	6.8	7.3	1917	768
	120	310	1.37	109	5.1	2900	6.6	7.7	2071	1226
13% sulphate-AQ	0	650	1.65	49	3.4	700	7.5	3.3	67	7.8
	30	490	1.41	92	4.6	1750	6.9	6.9	1248	104
	60	330	1.36	101	4.8	2520	6.5	7.6	1559	597
	90	280	1.35	110	5.2	2910	6.4	7.9	1671	891
	120	190	1.32	110	5.2	2930	6.3	8.1	2270	1879
14% sulphate	0	535	1.72	48	3.3	780	8.2	2.9	32	4.6
	30	575	1.50	95	4.7	2260	7.5	6.8	1138	32
	60	205	1.43	100	4.9	2480	7.4	7.3	1498	301
	90	145	1.39	104	5.1	2730	6.9	7.5	1838	676
14% sulphate-AQ	0	575	1.56	46	3.5	790	7.1	2.5	36	4.0
	30	335	1.47	94	4.7	2210	7.4	6.9	1179	73
	60	205	1.40	99	5.0	2440	7.0	7.2	1676	411
	90	150	1.40	105	5.1	2700	7.0	7.6	1882	1090
18% soda	0	615	1.80	45	2.9	630	7.1	2.5	22	2.9
	30	310	1.48	92	4.3	1930	6.7	6.0	473	80
	60	210	1.44	95	4.4	2050	6.4	6.4	820	260
	90	190	1.43	95	4.4	2070	6.4	6.5	942	267
18% soda-AQ	0	595	1.80	49	3.1	720	7.4	2.6	23	2.9
	30	345	1.49	90	4.2	1800	6.7	6.1	608	82
	45	230	1.43	90	4.2	1940	6.4	6.7	828	306
	60	200	1.38	92	4.4	2010	6.1	6.8	924	474
14% sulphate (bleached pulp)	0	515	1.63	49	4.1	1070	8.0	3.2	42	6.2
	70	185	1.38	102	4.8	2430	6.9	7.6	1287	375
14% sulphate-AQ (bleached pulp)	0	515	1.63	48	4.4	1140	7.8	3.4	43	10
	70	180	1.37	102	4.9	2510	6.9	7.4	1468	403

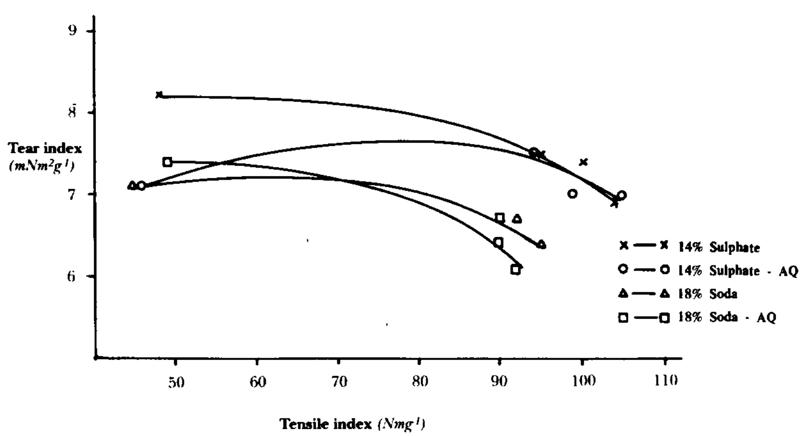

Figure 2. Relationship between tensile index and tear index of unbleached sulphate and soda pulps

Bleaching of sulphate and sulphate-AQ pulps at j number about 20 was conducted using CEDED sequence. The bleached sulphate-AQ pulp did not show any improvement over the bleached normal sulphate pulp in strength properties except for a slightly better folding endurance on beating. Two samples were used to determine the brightness stability (Table 4). Both pulps registered a loss in brightness by five points on ageing, corresponding to a low post colour number.

Table 4. Bleaching properties of sulphate and sulphate - AQ pulps at 14% active alkali

Sample	κ number	Bleach yield (%)	ISO brightness		Post colour number
			Before aging	18 *h* in oven (105°*C*)	
14% sulphate	21.4	93.7	86.4	80.7	1.23
14% sulphate - AQ	20.0	93.6	85.8	80.8	1.09

Conclusion

Pulping of oil palm fibrous strands using sulphate- and soda-AQ gave a slightly higher yield and lower j number compared to the normal sulphate or soda pulping. On the whole, the laboratory scale study showed that the fibrous strands responded well to sulphate-AQ or soda-AQ pulping which can be used to produce pulps of acceptable strength properties. However, in the use of oil palm trunk for pulp and paper production, preliminary separation of fibrous strands from the parenchymatous tissues is necessary for this raw material to be used effectively.

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the yield of teak established by taungya in the dry lowland rain forest area of Nigeria. It is hoped that the study will help the forest managers in assessing the performance of teak in the taungya system.

Methodology

Study data were collected from five unthinned stands of *T. grandis* (teak) located in the Gambari forest reserve, near Ibadan, Nigeria. The forest reserve is one of the largest reserves having a wide age range of teak plantations in the dry lowland rain forest area. It is located between latitudes 07° 05' and 07* 14' North, and longitudes 03° 42' and 03° 54' East. The average elevation of the area is from 120 to 150 *m* above sea level. The area receives approximately 1250 *mm* of rainfall annually and has a mean annual temperature of about 26.67°*C*. The soils are of the Ferruginous Tropical type underlain by undifferentiated Basement Complex rocks (Smyth & Montgomery 1962).

Five annual plantation series or stands of teak established by local taungya farmers and ranging in age from 9 to 25 years were used in this study. A uniform spacing of 2.4 × 2.4 *m* was used for the plantation establishment. Older plantations (*i.e.* plantations above 25 years old) were very few and they have been severely thinned. In each stand, five 25 × 25 *m* temporary sample plots were randomly selected for enumeration of the stand growth parameters. The plots were considered to have similar site quality. The measurements taken in each sample plot include the diameter at breast height (overbark) of all trees, merchantable height (to a fixed top diameter of 7 *cm*) of two mean trees whose basal areas were closest to the mean basal area, diameter (overbark) at 0.1, 0.3, 0.5, 0.7, and 0.9 positions of the total height of the two mean trees, and total height of the seven largest trees (representing the 100 largest trees per hectare).

The volumes of the mean trees were calculated using the Hohenadl's formula:

$$V = 0.2\,\pi/4 \quad (d_{0.9}^2 + d_{0.7}^2 + d_{0.5}^2 + d_{0.3}^2 + d_{0.1}^2) \qquad (1)$$

where,

V = Actual tree volume (overbark) in m^3,

d = Diameter overbark (in *m*) at the variously indicated positions along the stem.

Using the sample tree method, the volume of trees for the sample plot as well as the volume per hectare were calculated as follows:

$$V_{pi} = V_{mi} \times N_i \qquad (2)$$

where,

V_{pi} = Total volume of trees in the ith sample plot,
V_{mi} = Mean tree volume in the ith sample plot,
N_i = Number of trees in the ith sample plot.

For each age series (stand), the volume for all the sample plots were obtained and the mean computed. This was then used to estimate the volume per hectare for each stand.

For each stand,

$$V_s = \frac{\sum_{i=1}^{5} V_{pi}}{n} \qquad (3)$$

where,

V_s = Mean volume of trees in the stand, and
n = Number of sample plots in the stand.

The mean volume for the stand (V_s) is the volume for 1/16-*ha* plot. The volume of trees per hectare (V_h) was then obtained as equal to $V_s \times 16$.

Considering the narrow age range, it was not necessary to have sigmoidal or asymptotic relationship. Thus, a simple linear equation was considered appropriate for the stand volume age data. Since it is desirable and logical for the relationship to pass through the origin (*i.e.* volume = 0 when age = 0), the simple linear equation with zero intercept was fitted to the data. The analysis was done using the computer facilities at the International Institute of Tropical Agriculture (IITA), Ibadan.

Results and discussion

The stand volume per hectare obtained for the five stands showed a general increase with age as noticed from Table 1.

Table 1. Yield data for teak in the dry lowland rain forest area of Nigeria

Stand age (*y*)	Volume ± S.E.* (m^3 ha^{-1})	Top height** (*m*)	Number of plots
9	302 ± 18	12.0	5
13	333 ± 34	13.9	5
17	410 ± 20	16.0	5
21	607 ± 51	20.0	5
25	665 ± 39	20.7	5

* Stand volume to the nearest m^3 ± standard error

** Mean total height of the seven largest trees per plot (representing the 100 largest trees per hectare)

The volume-age equation fitted to the data is:

$$V = 27.0336A \qquad (4)$$

($r = 0.9966$; $R^2 = 0.9933$; RMSE = 44.4527)

where,

V = Stand volume ($m^3\ ha^{-1}$),
A = Stand age (y),
r = Correlation coefficient,
R^2 = Coefficient of determination, and
RMSE = Root mean square error.

From this equation (Equation 4), it follows that PAI = MAI = 27, where PAI and MAI are periodic and mean annual increments, respectively. This indicates that the optimum rotation age in terms of volume production is beyond the age range of the data used in this study.

The correlation coefficient of the equation is very high, thereby suggesting that within the age range of the data used in this study, the relationship between stand volume and age is linear. Although volume-age curves are basically sigmoidal (non-linear) in shape (Nokoe 1980), the age range covered in this study represents a fairly linear portion of the volume-age curve.

According to Steel and Torrie (1980), a linear relation is often a reasonably good approximation for a non-linear relation provided the values of the independent variables do not cover too wide a range. The coefficient of determination indicates that about 99% of the variation in stand volume of teak is accounted for by stand age. Thus, the stand volume in the study area can be estimated from stand age, using Equation 4, provided the stand age falls within the age range covered in this study.

The results of the study showed that teak plantations established by taungya in Nigeria maintain a fairly linear increment pattern during the first 25 years, averaging 27 $m^3\ ha^{-1}\ y^{-1}$. There were no signs that growth is slowing down, and it is too early to estimate optimum rotation age from the data. When compared with the Indian yield table, all the stands in the study area belonged to Quality Class I. This emphasizes the fact that teak is growing particularly well in the dry lowland rain forest area of Nigeria. The factors enabling such good growth of teak seem to be the climate (to which the species is well-adapted) and relatively good soils. Soils of the study area are among the most fertile soils in southern Nigeria.

Conclusion

The teak plantations established by taungya in the dry lowland rain forest area of Nigeria are doing well. Their yields compare favourably well with the yield in Quality Class I in India. Within the age range of the data used in the study, the zero intercept simple linear function is recommended for use when the stand volume of teak is to be computed from stand age.

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