Effect Of Refining Energy On the Pulp Properties Of Nonwoods

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ABSTRACT

Wheat straw and bamboo pulps were studied for their response to refining at various energy levels. The unbleached pulps of these nonwood raw materials were subjected to higher energy cycles (higher specific edge loads) and lower energy cycles (lower specific edge loads). The nonfibrous tissue in pulps that is subjected to higher energy cycles is damaged quickly resulting in rapid freeness drop and poor drainage properties of the pulps. The strength properties are also marginally low for the pulps put through higher energy cycles, in spite of better sheet consolidation levels as indicated by the apparent density values. The results indicate that the strength properties of the straw pulps can be improved without impairing the drainage property of the pulp significantly, if the pulps are subjected to lower energy cycles. These findings have significance, especially for the nonwood pulps where the drainage of the pulp is a limiting factor in nonwood fibre treatment. In spite of best possible fibre treatment, good quality kraft paper can not be made from straw pulp due to inherent low tear and burst strength. In such a situation, addition of secondary fibres from softwood source can be a better option to improve the properties of furnishes, where the major component in the mixture is straw.

INTRODUCTION

Fibres, due to their inherent characters such as morphology and chemical composition do not readily lend themselves for papermaking. Their bonding character has to be improved to enable fibre net formation. The physical process that is known as beating or refining can improve the bonding capability of the fibres.

Refining or beating is an important factor in papermaking process. The old papermakers used to say, 'the paper is made in the beater', which illustrates the significance of this process. Any damage done to the fibres at this stage can not be corrected elsewhere. Mechanical treatment to fibers alters fiber structure and influences the papermaking properties (Page, 1989). Changes in pulps that are brought in this way may be useful or detrimental to the papermaking and product quality. Stock preparation refining significantly contributes to papermaking process by effecting the runnability of the stock and quality of product. A correct approach towards refining

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treatment is very essential for energy savings and product with desired properties.

Refining of chemical pulps fibres is carried out to prepare the fibres in such way that they are optimally developed for the production of a given paper grade. The response of different fibres to refining varies. Refining develops various fibre properties in different ways and the purpose is to achieve maximum desirable effects with minimum undesirable effects (Heitenan and Ebeling, 1990). It means to keep the drainage resistance of the pulp low and at the same time improve the fibre bonding without reducing the intrinsic fibre strength. The basic idea is to treat the pulp in such way that we achieve the combination of desirable properties in the final product. In the ideal case, we will be looking for a pulp where all the fibres are treated to the same degree in a uniform manner.

The complex nature of the nonwood fibre pulps throws greater challenges to the refining process. Nonwood fibres are generally short and slender and accompanied by high proportion of nonfibrous elements (Krishnagopalan and Simrad, 1976). Nonwood pulps are weak, heterogeneous and have a high nonfibrous content. In fact the usage of nonwoods for papermaking has not been fully understood.

The performance of a refined pulp in papermaking process is difficult to predict based on the beating data obtained in laboratory and the laboratory beaters are not representative of mill refiners. These studies will help to optimise the process conditions and energy requirement for pulp on refining under simulated mill conditions. The experiments help to establish the requirement of specific edge load for refining of pulp and optimisation of energy requirement for achieving desired properties.

The results being discussed in the following test are the results for the dried and rewet pulps. Strength properties for the undried virgin pulps will be superior compared to the dried and rewet pulps (Kibblewhite, 1989). And also the properties for the paper made on paper machine would be better compared to the handsheets made in the laboratory under similar refining conditions.

MORPHOLOGY OF THE FIBRE SOURCES

Different morphological regions of nonwoods were microscopically examined for estimation of tissue composition (Table 1). Wheat straw pulp has fibres, parenchyma, vessel and epidermal cells. The fibres are remarkably uniform and straight with rather thick walls and sharp pointed tapering ends. The fibres vary in length from 0.6 to 4.5 mm (average of 1.2 mm). In width they are very much narrower ranging mostly from 8 to 25μ (average 13μ). Rectangular and barrel shaped parenchyma cells are abundant and often present in masses/individuals. They range from very small to big measuring 300μ (average 237μ) in length and 20 to 100μ (average 50μ) in width. Vessels are fairly long but very much narrower in width varying from 21 to 100μ (average 61μ).

Bamboos are tropical plants that are separated into a number of genera, which account for several hundred species. They are woody in the sense of hardness of their tissues and structurally they are typical of the grass family to which they belong. The elements of bamboo pulps are similar to those of wheat straw and other grasses. The fibres are much longer and epidermal cells are not usually present. The dimensions of pulp elements of typical bamboo are as follows. Fibres are from 1.45 to 4.35 mm (average 2.7 mm) in length, and 6.8 to 27.3μ (average 15.0μ) in width. The parenchyma cells are up to 0.25 mm long with a maximum width of 65μ. The vessel segments are up to 100μ in widht.

PROPERTIES OF NONWOOD PULPS

Properties of the virgin pulps significantly influence the pulp behavior in refining. These properties furnished in the Table-1, are inherent and can not be changed. the only way to tackle this

Table-1

Fibre dimensions and fibre, vessel and parenchyma cells proportions

Material	Fibre %	Parenchyma %	Vessel %	Fibre length (mm)	Fibre diameter (μm)	Specific surface (cm^2/g)	WRV %
Wheat straw	25	75	3	1.2	13	20	170
Bamboo	55	40	5	2.7	15	14	110

problem is either by modifying the pulp composition or by improvising the refining parameters in such a way that the undesirable effects are minimised.

TERMINOLOGY USED IN THE REFINING PROCESS

The advent of modern theories on refining took beating or refining of pulps from an art to science. These theories allowed the action of a refiner to be quantified in terms of severity and duration of treatment. The early theories of refining were developed in 1960s and 1970s. Of these theories the Specific Edge Load theory (Breacht and Siewart, 1966), although not covering all aspects of refining, for example, bar angle is the easiest to apply and has gained credibility with most refiner and pulp suppliers, research institutes and papermakers.

i. Specific energy

The specific energy results from the power related to the stock throughput per time unit. A distinction is made between the total and the net specific energy. Since the laboratory refiner works in recirculation operation, the energy transmitted to the raw material between two samplings is established as follows

$$\Delta A_s = (P*\Delta t)/M_{Rest} \quad (1)$$

The energy transmitted during refining A_s is obtained for

$$A_s = \Sigma \Delta A_s \quad (2)$$

in equation (1)

M_{Rest} Stock quantity, which is in the system until samples are taken.

Δt Time between start of trial and sampling and/or between two samplings.

P For "total spec.energy", the power absorbed is used here.

P_e For "net spec.energy", the net refining load is used.

ii. Idle load Power P_o

The idle load power P_o includes the hydraulic losses of the machine. It is established with water for the corresponding throughput and speed at 1-mm bar distance.

iii. Net refining load P_e

The net refining load is the difference from the power absorbed and the idle load power.

iv. Edge length per second L_s

The edge length per second shows the cutting length per time unit (s), and/or the cutting speed. It is calcuated from

$$L_S = Z_R * Z_S * I * n/60$$

Where

Z_R = no.of rotor bars

Z_s = no.of stator bars

l = bar length

n = speed of disc

v. Specific edge load (SEL)

The specific edge load shows the bar edge load ie. the net refining work P_e is related to the edge length per second L_S.

$$B_S = \frac{P_e}{L_S} = \frac{P - P_o}{L_S}$$

MATERIALS AND METHODS

1. Refining of Wheat straw pulp using two refining loads.
2. Refining of Bamboo pulps with two refining loads.
3. Refining of secondary fibre with 1.0 ws/m specific edge load.

Air-dried ubbleached wheat straw pulp of kappa no 22 was slushed to 4% consistency. This pulp was refined in Escher - Wyss laboratory refiner using 0.5 and 0.75 ws/m specific edge loads. The air dried bamboo pulp was slushed also to 4% consistency and refined in laboratory refiner using 1.0 and 1.5 ws/m specific edge loads.

REFINING OF PULP IN ESCHER-WYSS LABORATORY REFINER LRL

REFINING PARAMETERS

I.	Stock quantity	1000 to 1900 g BD
II.	Stock consistency range	4%
III.	Specific edge load	0.5 to 1.5 ws/m
IV.	Test duration	5-20 min
V.	Operation pressure	0.5-3.0 bar

All the samples were in air dried condition. Moisture for these air-dried samples was determined in duplicate. No load power was determined using water and 1 mm plate clearance by operating the calibration routine just prior to each experiment. Refining experiment with pulp was carried out under the same conditions that were used in the calibration. Each experiment was carried out using approximately 1000g pulp (on bone dry basis). The air dried pulps were slushed in 25 liters of water to obtain desired consistency and given about 7 to 10 min pulping time. Following general conditions were used in all the experiments.

i)	Disc refiner	Single disc refiner
ii)	Disc pattern	3-1.12-60
iii)	Disc diameter	152 mm (6 inch)
iv)	R P M	2000
v)	Peripheral speed	943 m/min
vi)	Edge length	1120 m/s
vii)	Specific edge load	0.5, 0.75, 1.0, 1.5 ws/m
viii	Consistency	4%
ix)	Flow rate	100 ml/min.
x)	Net specific energy applied	0, 25, 50, 100 kwh/t
xi)	Sample collected	1 liter

Hand sheets of 60 gsm were made on British sheet former as per ISO DP 5269. Strength properties for the hand sheets were determined using standard ISO methods.

STANDARDS FOLLOWED

Kappa number	T-236-OS-76
Freeness (ml Csf)	ISO-5267/2
Handsheet preparation	ISO-5269/1
Burst index	ISO-2758
Tensile index	ISO-1924
Tear index	ISO-1974
Porosity	T-547-pm-88

RESULTS AND DISCUSSION

Refining of nonwood pulps

Wheat straw (WS) and bamboo (B) pulps are analysed to understand that how these pulps respond to different refining intensities (energy cycles). It is generally observed in wood pulps that the freeness development is slower when they are refined with higher specific edge loads (high energy cycles). The higher specific edge loads lead to fibre cutting but not fibrillation (Baker, 1991), hence the freeness drop of the pulp is restrained. The straw pulps normally do not require higher refining intensities. In case of wheat straw pulp, it is observed that the freeness drop is rapid in the pulp refined at 0.75 ws/m compared to the pulp refined at 0.5 ws/m (Fig. 1). Similarly

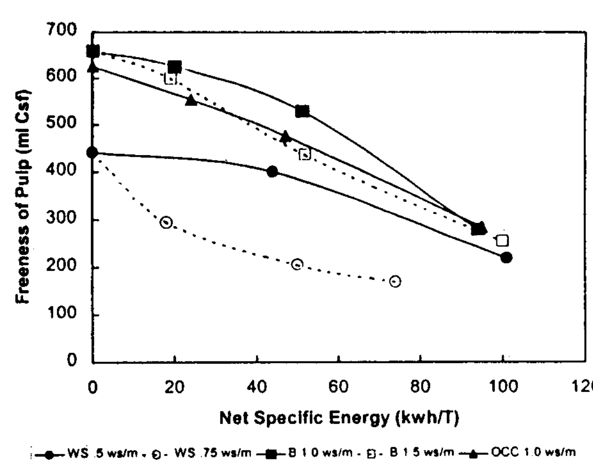

Figure 1. Effect of refining intensity on freeness of pulp.

the bamboo pulps also responded, but the pulps refined at 1.0 ws/m has only shown marginal improvement in freeness compared to that of the pulp refined with 1.5 ws/m at given net specific energy levels upto 100 kwh/t. It indicates that the enhanced levels of freeness drop in nonwood pulps at higher specific edge loads (Baker, 1997) is due to breakdown of the paranchymatous groups in to single cells as primary fines (Subrahmanyam et al., 1999) and their further disintegration as debris.

The drainage values for the wheat straw and bamboo pulps are lower when refined with lower specific edge loads (Fig. 2). The drainage character of the pulp deteriorates, as these two nonwood pulps are refined using higher specific edge loads (high-energy cycles) Baker, 1997). This is due to rapid release of single cells from groups of parenchyma and/ or disintegration of parenchyma in pulps refined with higher specific edge loads.

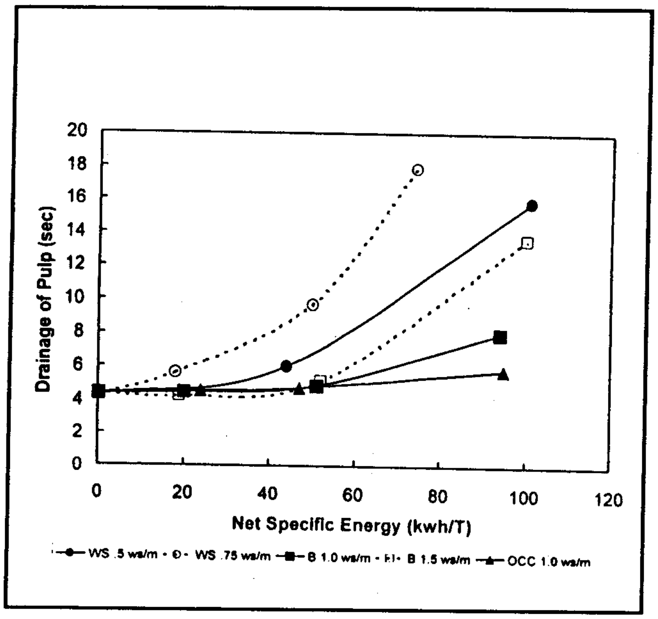

Figure 2. Effect of refining intensity on drainage property of pulp.

The apparent density values are marginally higher in both wheat straw and bamboo pulps when refined at higher specific edge loads (Fig. 3). Apparent density indicates the handsheet consolidation. Sheet consolidation can be increased by

a) fibre collapsibility

b) Increase in particulate matter.

Fibre collapsibility in handsheet increase up on

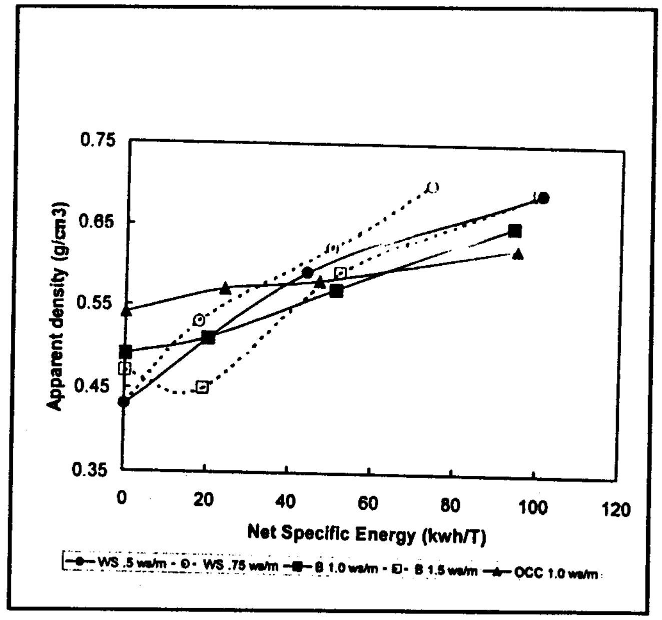

Figure 3. Effect of refining intensity on Sheet density.

refining due to improved fibre Swelling (Kibblewhite, 1989). Origin of the particulate matter is different in less fibrous pulps and more fibrous pulps. In more fibrous pulps the particulate matter is generated from the separation of fibrillar matter from the fibres, which is known as secondary fines or fibrillar fines. In less fibrous pulps (mostly nonwood sources) the particulate matter is generated initially by separation of groups of parenchymatous tissue primary fines).

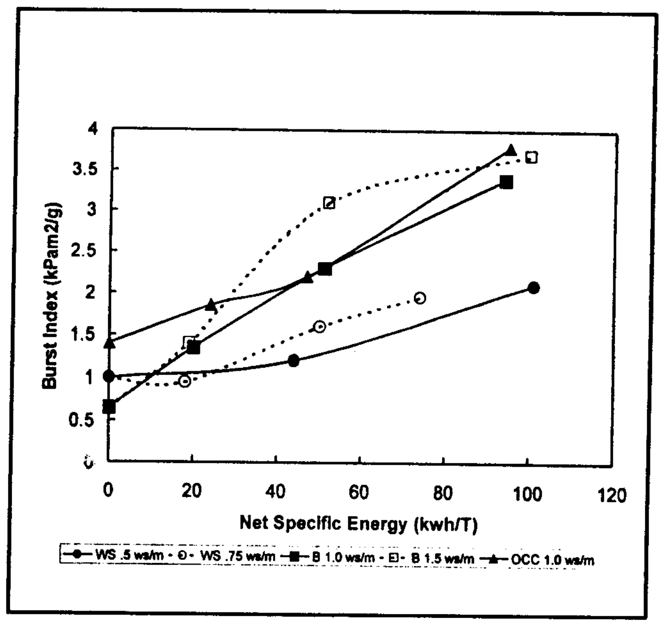

Figure 4. Effect of refining intensity on Burst index.

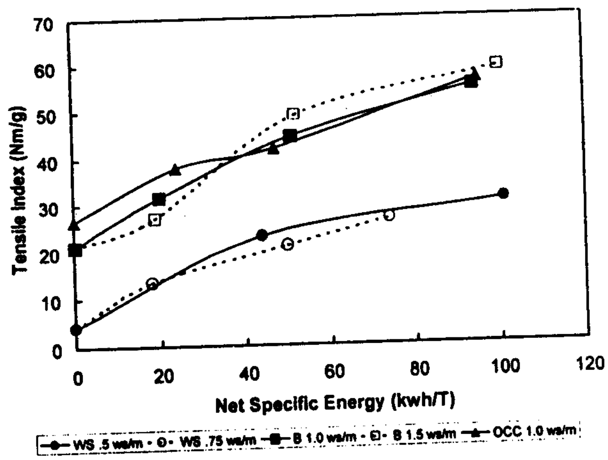

Figure 5. Effect of refining intensity on tensile strength.

and latter by their degeneration (Roy et al, 1994 and Subrahmanyam et al., 1999). The parenchyma cells are very thin walled and susceptible for degeneration due to excessive mechanical action (Subrahmanyam et al., 1994; Cheng et. al., 1994 Jacobs and McKean, 1997 and Zhai and Lee, 1989). It may be observed in the present experiment that the sheet consolidation is on the higher side for the pulps refined at higher intensities, indicating the disruption of the parenchyma and their further degradation resulting in filling up

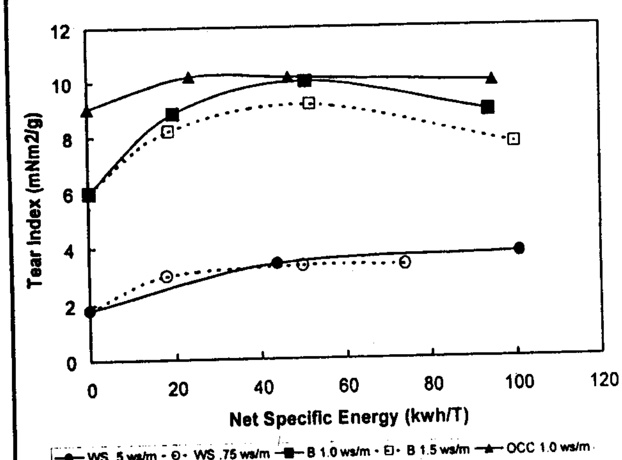

Figure 6. Effect of refining intensity on tear strength.

of the voids in the paper structure.

The straw pulp refined with two specific edge loads has poor burst development (Fig. 4). Strength properties like tensile (Fig. 5) and tear (Fig. 6) index are normally directly proportional to the sheet density. But in the wheat straw and bamboo pulps, the strength properties like tensile and tear index are marginally higher for the pulps refined at lower specific edge loads (low energy cycles). This indicates the preservation of intrinsic fibre strength of the pulps refined with lower intensity refining.

The porosity values drop stop steeply for the pulps refined at higher specific edge loads (Fig. 7). This is perhaps due to filling up of the void spaces

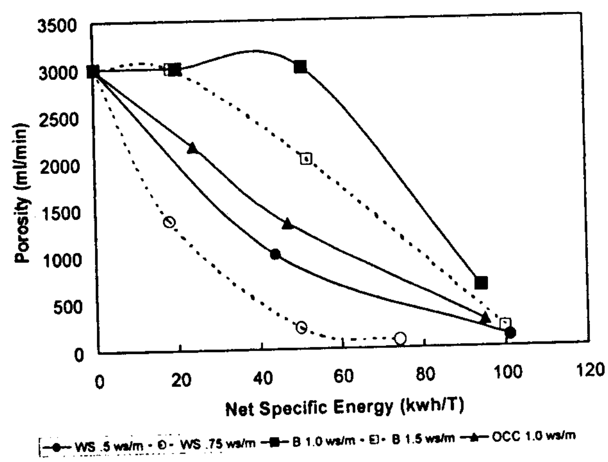

Figure 7. Effect of refining intensity on sheet porosity.

in the sheet by the single parenchyma cells and degenerated parenchyma cell wall matter.

REFINING OF SECONDARY FIBRE PULPS

Secondary fibre pulp from old corrugated containers (OCC) was refined at 4% consistency (Figures 1-7). These fibres are recycled fibres and would have gone through the refining process at least once prior to the present studies. Hence, these fibres may not withstand higher refining intensities. Keeping this in view the OCC pulp was refined with 1.0 ws/m specific edge load. This pulp has an initial freeness of 625 ml CSF which has dropped to 285 ml CSF on refining to the net specific energy level of 95 kWh/t. Drainage property of the pulp is not deteriorated up to a net specific energy level 95kWh/t. Tensile strength has improved on refining to 56.5 Nm/g. The pulp has a burst index of 3.8 $kPam^2/g$ at the net specific energy level of 95 kWh/t. Porosity value is maintained at 285 ml/min on refining to the net specific energy level of 95kWh/t.

IMPROVING THE PROPERTIES OF STRAW PULPS

Strength properties of the straw pulps are low in general. Burst strength is especially low and recorded at 2.1 $kPam^2/g$. To improve the properties of the kraft papers made of straw pulps, Hessian pulp is added. Refining requirement for Hessian pulp is entirely different from that of the straw pulps. Blending of two pulps with extremely different refining requirement is not advised.

The pulps are blended either before or after refining treatment. In the mixed pulp refining, bulk of the treatment is received by coarser fibres (Baker, 1997; Subrahmanyam, 1999). In separate refining, the individual pulps are refined to their best properties due to homogeneity. Separate refining is normally advised, however it may not be practical in small mills. In such a situation, it is advisable to blend the pulps having similar, if not exactly same refining requirement. In our experiments, we have observed that the secondary fibres from old corrugated containers have lower refining requirements like straw pulps.

Prediction of the refining effects of different mixtures can be made with help of 'linear blending theory' (Baker, 1997). The properties of the mixed pulps can be calculated using the following equation for two pulps:

Property (AB) = % Property A+% Property B

However, linear blending theory shall be applied with great caution becuase:

- Coarser fibres protect the finer fibres in the blends.
- The properties of the blends like bulk and porosity are normally close towards the component pulp with lowest properties.

In the present calculation, we have used the wheat straw refined using 0.5 ws/m and old corrugated container pulp refined using 1.0 ws/m specific edge loads. Both the pulps were refined to about 100 kWh/t net specific energy levels and the results are furnished in Table-2. When 25% of secondary fibre is added to furnish, the drainage property improved by about 16%. The properties of the blends predicted shows encouraging trend. The tearing strength of the pulp can be improved 41% on straw pulp basis. The tensile strength can be improved by 21% and porosity by 36%. These results indicate that the secondary fibre can be used to improve the overall performance of the furnish, where the straw is the major component.

CONCLUSIONS

- Refining of nonwood pulps, in particular straw pulps with higher specific edge loads leads to

Table-2

Refining results based on linear blending theory.

Pulp blend	Units	Straw Pulp (A)	OCC pulp (B)	A : B 3:1	A : B 1:1
Freeness	CSF	220	285	236.3	252.5
Drainage Time	sec	15.85	5.79	13.3	10.8
Apparent Density	g/cm^3	0.69	0.62	0.67	0.66
Burst Index	$K.Pam^2/g$	1.2	3.8	1.85	2.5
Tensile Index	Nm/g	30.5	56.5	37.0	43.5
Tear Index	mNm^2/g	3.75	9.95	5.3	6.9
Porosity (Bend)	ml/min	115	280	156.3	197.5

rapid disintegration of nonfibrous tissue resulting in faster freeness drop and increased drainage times.

- Refining of straw pulps with lower specific edge loads deters the disintegration of nonfibrous tissue and allow improved fibre swelling resulting in improved strength properties.
- Addition of secondary fibres from softwood source to straw pulp is a better option to improve the furnish properties.

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