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Studies on the properties of alkali-treated jute-modacrylic flyer-spun yarns

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Jute and jute-modacrylic yarns of various blend ratios have been prepared and treated with different concentrations of NaOH (5% -22% w/w). It is observed that this treatment results in axial shrinkage and weight loss of the yarns. The axial shrinkage increases with the increase in NaOH concentration up to 18% whereas the weight loss increases with the increase in NaOH conc. up to 22%. Even though the tenacity and modulus of yarns decrease substantially on alkali treatment, the work of rupture increases after treatment which is mainly due to the increase in breaking elongation. Statistical analysis shows that the modulus of different strain levels and tenacity values are positively and significantly correlated with the packing fraction values of the yarns. Blending of modacrylic fibre with jute does not show any appreciable improvement in bulk property of yarn. However, the whiteness index and mean gray value of alkali-treated blended yarns confirm the improvement in appearance of the yarns due to the preferential migration of modacrylic fibres on the surface of the yarn.

Keywords: Axial shrinkage, Flyer spinning, Jute, Modacrylic, Modulus, Packing fraction, Tensile properties, Whiteness index

1 Introduction

It has been established by several workers[1-6] that the jute develops crimp when is treated with sodium hydroxide solution (Woollenization). The number and wave length of crimps increase with the increase in concentration of sodium hydroxide up to 18% and beyond this concentration the proneness of effect on fibre is much less[6]. The treatment with sodium hydroxide solution up to 10% (w/w) of its concentration cannot produce pronounced crimp in jute fibre[7]. It was observed[7] that the crimp profile is neither helical nor follow any regular pattern. The blending of alkali-treated jute fibre with other fibres like wool was used for the development of carpet and blanket[7]. But, it was observed that the crimp of alkali-treated jute fibres gets destroyed while processing it in the jute processing machinery. Later, Sinha *et al.*[8] studied the changes in physical properties after treating the 100% jute and jute/polypropylene blended yarns with 18% (w/w) sodium hydroxide solution. It was observed[9] that the simultaneous torque decay and shrinkage-cum-crimp of the jute fibre result in partial destruction of helical structure of the spun jute yarn. They also reported that the treatment of jute/polypropylene (80:20) blended yarn with alkali results in the migration of high shrinkage jute fibre towards the core, while the non- shrinkable polypropylene fibres migrate towards the surface of the yarn and form loops and kinks there. Gupta *et al.*[10] studied the effect of chemical texturization on different blend levels of jute and polypropylene fibre, alkali concentration, and treatment, and found that the 60:40 jute/polypropylene gives maximum bulk at 18% sodium hydroxide. Sinha *et al.*[11] compared the properties of jute/ polypropylene (80:20 and 60:40) blended yarns with those of 100% jute yarn after alkali treatment. It is to be noted that the polypropylene fibre is not responsive to dyeing.

It was, therefore, decided to explore the possibility of producing bulked yarn from jute/non-shrinkable modacrylic blended yarn. Manufacturing of bulked yarns from the binary blend of high shrinkable and non-shrinkable modacrylic fibres using thermal treatment is an age old practice in the industry. Modacrylic, being a low density fibre, possesses very good thermal insulation property. The modacrylic fibres are resistant to alkali even up to 50% concentration at 50°C temperature for. 20 h treatment[12]. It has been observed that the blend ratio of high-shrinkable and

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non-shrinkable components significantly influences the property of the yarn[13].

In this study, jute/modacrylic yarns of various blend ratios have been prepared in conventional jute sliver spinning system. Texturization was carried out by treating the yarn with various concentrations of NaOH (5%-22% w/w). The changes in physical properties of the yarns treated at each level of NaOH concentration were analysed.

2 Materials and Methods

2.1 Materials

Jute fibre (TD-3 grade[14]) and non-shrinkable modacrylic fibre top were used for the Study. The details of the fibres are given in the Table 1. Sodium hydroxide pellets (L R grade) were used for texturization of the yarns.

2.2 Methods

2.2.1 Preparation of Yarn

The raw jute fibres were processed through the softener machine, sprayed with oil-in- water emulsion and piled for 48 h. The jute reeds were then processed through conventional commercial jute spinning system with three passages of drawing. Jute third drawing sliver and modacrylic top were blended in Mackie's screw gill jute first drawing frame. To achieve homogeneous blend, an extra passage of drawing was given with equal draft and doubling. All the yarns of nominal linear density (160 tex) were spun in Mackie's Apron draft flyer spinning frame with 236 tpm.

2.2.2 Alkali Treatment

Yarn hanks were treated in relax condition with 5 different concentrations of sodium hydroxide (5%, 9%, 12%, 18%, and 22% w/w) at room temperature for 45 min. The material -to- liquor ratio was maintained at 1: 20. The treated yarns were thoroughly washed with normal water, neutralized with 1.5% acetic acid solution, again washed with normal water and then dried at room temperature.

Table 1 — Physical properties of fibres

Fibre	Colour	Linear density tex	Tenacity cN / tex	Breaking extension %
Modacrylic	White	0.16	24	30.0
Jute	Natural colour	2.10	45	1.5

2.2.3 Measurement of Shrinkage

The shrinkage percentage was evaluated from the length of the yarn before and after treatment using a pre-tension of 0.18 cN/tex.

2.2.4 Measurement of Weight Loss

The weight loss (W) was measured from the weight of yarn hank before and after the alkali treatment for each sample using the following relationship:

$$W\ (\%) = \frac{W_u - W_t}{W_u} \times 100$$

where W_u and W_t are the weights of untreated and treated yarns respectively in grams.

2.2.5 Evaluation of Tensile Properties

The tensile properties of the conditioned samples were measured in Zwick universal tensile tester with 500 mm test length at a strain rate of 300 mm per min and a pre-tension of 0.1 N.

2.2.6 Evaluation of Bulk Density and Packing Fraction

The bulk density (d_b) of the yarns was calculated from the following relationship:

$$\text{Bulk density}\ (d_b) = \frac{1.24 \cdot \text{tex} \cdot 10^{-5}}{d_y^2}$$

where d_y is the diameter of the yarn in cm. The diameter of the yarn was measured in a projection microscope with a magnification of 40× under constant tension.

The packing fraction (ϕ) of the yarns was calculated from the following relationship:

$$\text{Packing fraction}\ (\phi) = \frac{d_b}{\rho}$$

where d_b is the bulk density and ρ, the fibre density. The ρ of the blended yarns was calculated from the following relationship:

$$\text{Fibre density of the blended yarn}\ (\rho) = \frac{\rho_a \rho_j}{P_j \rho_a + P_a \rho_j} \times 100$$

where P_j and P_a are the percentage of jute and modacrylic fibres respectively and ρ_j and ρ_a, the densities of jute and modacrylic fibres respectively.

2.2.7 Measurement of Whiteness Index, Yellowness Index, Brightness Index and Mean Gray Value

The whiteness index (Hunter lab scale), yellowness index[15] and brightness index (TAPPI 45) of the samples were measured using Macbeth - 2020 plus computer match prediction system. The image analysis method was adopted to evaluate brightness of the yarn surface using the computer software "Optimus 5.2"and HP Scanjet 4C Flat-bed scanner.

3 Results and Discussion

3.1 Effect of Alkali Concentration on Weight Loss, Shrinkage and Packing of Yarn

The treatment of jute and jute/modacrylic blended yarns with various concentrations of sodium hydroxide shows length-wise shrinkage in yarns. Fig.1 shows that the weight loss increases with the increase in alkali concentration. The weight loss occurs mainly due to the partial removal of hemicellulose, pectins and jute batching oil (JBO) from the jute fibres. Therefore, the weight loss decreases with the decrease in percentage of jute component in the blended yarns for the same concentration of alkali. The 100% modacrylic yarns treated with 22% sodium hydroxide solution show negligible weight loss (1.8%). Fig. 2 reveals that the length-wise shrinkage of all the yarns increases up to 18% conc. of sodium hydroxide and then it almost levels off. It is also observed from Fig. 2 that at the same concentration of alkali, the extent of shrinkage decreases with the decrease in percentage of jute fibres in the blended yarns. The 100% modacrylic fibres do not show any noticeable shrinkage (0.4%) on treatment with 22% NaOH. The contractile force generated due to the development of crimp in the jute fibre is responsible for the length-wise shrinkage in alkali-treated yarn. Therefore, the decrease in quantity of jute fibres in the blended yarns results in lower contractile force, which ultimately reduces the shrinkage value.

Alkali treatment of jute and jute/modacrylic yarns decreases the packing fraction of the yarns (Fig. 3). The development of crimp in the jute fibre due to alkali treatment results in an outward pressure along the right angle to the yarn axis to create spaces to accommodate three dimensional crimps, thereby causing the reduction in tightness of the fibrous assembly. In case of blended yarn, the incorporation of modacrylic fibres improves the bulkiness of untreated yarn to quite a remarkable level. This is apparently due to the use of low density modacrylic fibre and dissimilar surface property of component fibres. Moreover, modacrylic fibres being much finer than jute preferentially migrate towards the core during yarn formation at the spinning stage. After texturing at 22% NaOH conc., the packing coefficient values of all the blended yarns are found to be similar to that of 100% jute yarn (Table 2), i.e. the improvement in bulkiness of blend yarn after texturing is much less than that in 100% jute yarn. This is due to the decrease in number of crimpable jute fibres in the blend yarn which results in generation of less lateral force during texturing of the yarn. It may also be assumed that the non-shrinkable component (modacrylic fibres) does not contribute appreciably in improving the bulkiness by forming loops or kinks as happens in conventional 100% modacrylic bulked yarn. The modacrylic fibres, preferentially situated at the core, are pushed outward by the jute fibres towards the surface of the yarn. Thus, extra length of the modacrylic fibres available due to the shrinkage of yarn is utilized to move the modacrylic fibres in a greater path from core to sur-

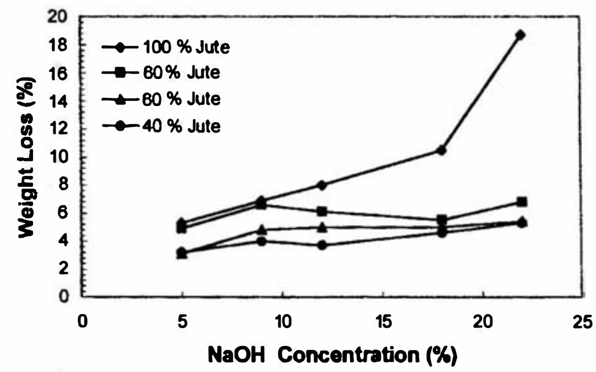

Fig. 1 — Relationship between weight loss and alkali concentration with the change in proportion of jute fibres in the blended yarns

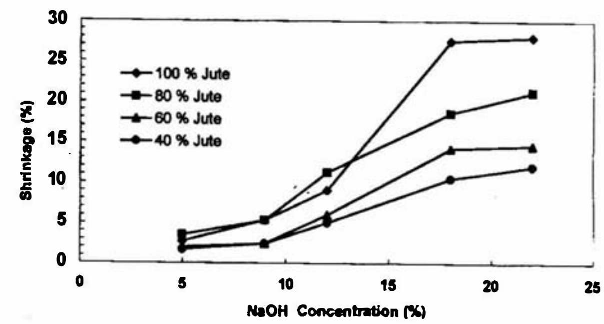

Fig. 2 — Effect of alkali conc. on shrinkage behaviour of yarns

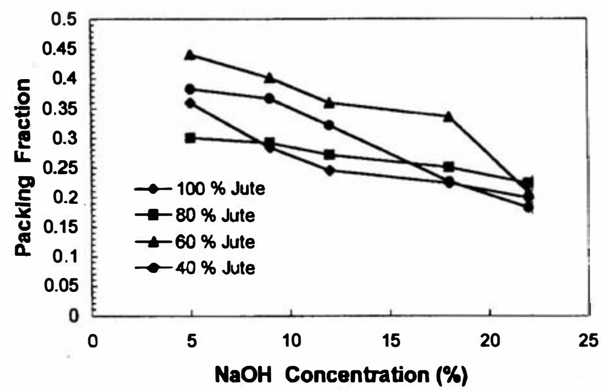

Fig. 3 — Effect of alkali conc. on packing fraction of yarns

Table 2 — Physical properties of untreated jute/ modacrylic yarns

Blend ratio (Jute: Modacrylic)	Tenacity cN/tex	Strength CV%	Extension at F_{max}, %	Extension CV%	Specific work of rupture mJ/tex.m	Packing coefficient
100:0	12.10	21	1.17	16	0.75	0.777
80:20	11.73	18	1.30	18	0.64	0.449
60:40	12.00	16	1.63	17	1.05	0.470
40:60	8.25	25	2.76	22	0.77	0.424

Table 3 — Whiteness index, yellowness index, brightness index and mean gray value of the yarns

Blend ratio (Jute:Modacrylic)	Untreated yarn				Treated yarn							
					18% NaOH				22% NaOH			
	WI	YI	BI	MGV	WI	YI	BI	MGV	WI	YI	BI	MGV
100:0	59.6	32.4	32.4	106.2	57.0	23.0	30.0	96.0	56.9	31.3	29.9	97.6
80:20	60.1	29.0	33.2	124.4	58.9	25.1	32.1	119.7	59.3	22.0	33.1	119.7
60:40	61.9	27.4	33.7	144.6	62.8	18.4	38.0	148.6	62.2	19.9	36.6	141.2
40:60	64.1	29.0	38.0	149.9	63.7	25.1	38.8	152.5	65.6	22.0	41.2	153.5
0:100	74.2	27.4	54.9	—	—	—	—	—	—	—	—	—

WI — Whiteness index (HUNTER lab scale)
YI — Yellowness index (ASTM D1925)
BI — Brightness index (TAPPI 145)
MGV — Mean Gray Value (OPTIMUS 5.2) in which 0 (zero) means full dark and 255 means full bright

face and surface to core. Table 3 shows that the alkali treatment causes increase in whiteness index of the blended yarn. The increase in percentage of modacrylic fibres in the blended yarn results in higher whiteness index for both untreated and alkali-treated yarns. The increase in alkali concentration from 18% to 22% does not improve the whiteness of the yarn samples. A similar trend has also been observed from results of image analysis of treated (18% and 22% NaOH) and untreated yarns (Table 3). The alkali treatment causes the increase in brightness of the blended yarns. This is due to the migration of acrylic fibre onto the surface of yarn during alkali treatment. Therefore, it may be concluded that the increase in whiteness indices as well as brightness of the blended yarns confirms the phenomenon of preferential migration of modacrylic fibres towards the yarn surface due to alkali treatment.

3.2 Effect of Alkali Treatment on Tensile Properties

Alkali treatment causes a remarkable loss in tenacity and initial stress at different extensions, and simultaneously remarkable increase in elongation of all types of yarns as shown in Fig. 4, Table 4 and Fig. 5 respectively. Samajpati *et al* [7]. observed that on alkali treatment the specific stress of jute fibre remains un-

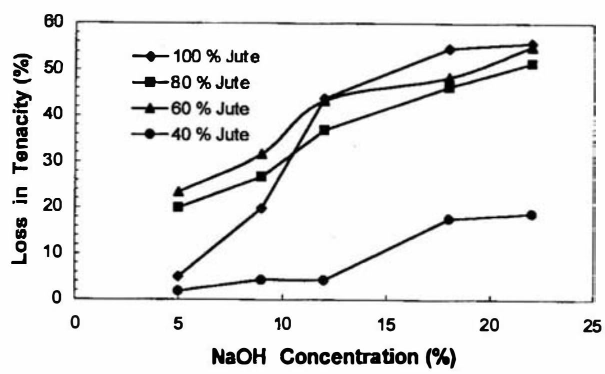

Fig. 4 — Effect of alkali conc. on loss in tenacity of yarns

changed. Therefore, the loss in tenacity may be attributed to the partial destruction of helical structure of the yarn alongwith irregular entanglement of fibres within the yarn matrix[9] and consequently loosening of yarn structure. The reduction in initial modulus may also be due to the above facts. Table 4 shows that the stress at every level of strain decreases with the increase in alkali conc. On statistical processing of data, it has been revealed that the initial stress levels are highly correlated with the packing coefficients (Table 5). Therefore, it may be stated that apart from the inherent tensile and surface properties of the fibres, the packing density of the yarn plays the most important role in determining the initial modulus of the yarn and

Table 4 — Modulii at different extension levels of jute and jute/ modacrylic yarns treated with different concentrations of alkali

Blend ratio (Jute:Modacrylic)	Alkali conc. %	Modulus, cN/tex 0.1[a]	0.25[a]	0.50[a]	0.75[a]	1.0[a]	1.5[a]	Modulus at break cN/tex
	Untreated	1.30	2.92	5.20	7.45	10.25	-	12.10
	5	0.61	0.82	1.30	2.01	2.88	5.36	11.50
100:0	9	0.55	0.70	1.06	1.50	2.01	3.55	9.70
	12	0.49	0.62	0.87	1.19	1.52	2.47	6.80
	18	0.42	0.50	0.64	0.79	0.96	1.40	5.50
	22	0.36	0.38	0.42	0.50	0.58	0.64	5.30
	Untreated	0.86	1.62	2.59	3.30	5.86	8.70	11.73
	5	0.59	0.75	1.10	1.56	2.12	3.71	9.40
80:20	9	0.56	0.69	0.95	1.30	1.71	2.86	8.60
	12	0.54	0.68	0.93	1.28	1.67	2.78	7.40
	18	0.44	0.52	0.63	0.76	0.90	1.23	6.30
	22	0.42	0.45	0.51	0.66	0.85	0.95	5.70
	Untreated	0.83	1.05	1.82	2.73	3.68	5.80	11.00
	5	0.56	0.70	1.02	1.37	1.78	2.86	8.50
60:40	9	0.51	0.61	0.82	1.10	1.46	2.45	7.50
	12	0.57	0.72	1.03	1.38	1.80	2.88	6.30
	18	0.44	0.51	0.64	0.79	0.96	1.35	5.70
	22	0.47	0.53	0.63	0.88	1.17	1.34	5.00
	Untreated	0.67	0.95	1.55	2.28	2.94	4.45	8.40
	5	0.60	0.72	0.97	2.27	1.59	2.40	8.25
40:60	9	0.68	0.90	1.23	1.56	1.95	2.82	7.90
	12	0.57	0.68	0.92	1.21	1.51	2.27	7.90
	18	0.54	0.52	0.57	0.58	0.61	0.63	6.80
	22	0.55	0.62	0.78	1.01	1.30	1.51	6.70

[a] Strain (%)

Table 5 — Correlation coefficient between packing coefficient and stress at different strain levels of the yarns

Blend ratio (Jute:Modacrylic)	Correlation coefficient 0.1[b]	0.25[b]	0.5[b]	0.75[b]	1.0[b]	1.5[b]	At break
100:0	0.997	0.993	0.995	0.997	0.999	0.992	0.769
80:20	0.983	0.990	1.000	0.994	0.990	0.993	0.947
60:40	1.000	0.720	1.000	0.690	0.677	0.760	0.881
40:60	1.000	0.834	0.840	0.814	0.796	1.000	0.979
All yarns[a]	1.000	0.881	0.891	0.895	0.878	0.723	0.728

[a] Considering different yarns alltogether
[b] Strain (%)

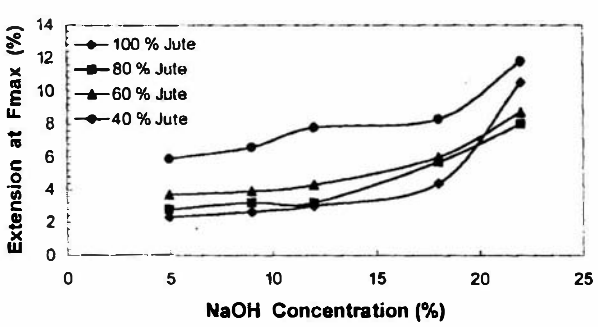

Fig. 5 — Effect of alkali conc. on breaking extension of yarns

this is true for all types of yarn samples. The closer packing of fibres causes more lateral pressure of the fibre bundle towards the yarn axis during longitudinal loading of the yarn which helps to increase the inter-fibre friction, thereby restricting the inter-fibre slippage at small strain.

The yarn tenacity values are also closely associated with the packing coefficient values but the degree of association between these two variables is lower than that of between packing coefficient and initial modulii (Table 5).

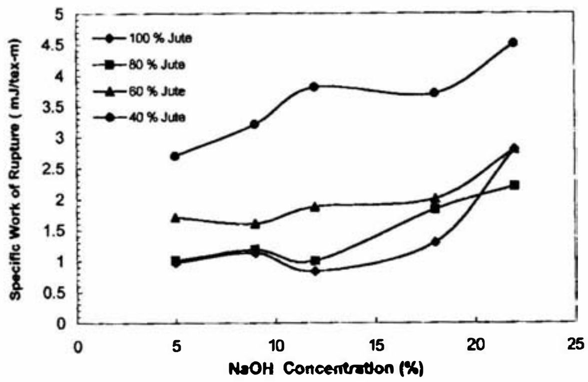

Fig. 6 — Effect of alkali conc. on work of rupture of yarns

Fig. 4 shows that all the yarns, except 40:60 jute/modacrylic yarns, show more or less similar trend for loss in tenacity after alkali treatment. The loss in tenacity of 40:60 jute/modacrylic yarn is found to be much less than those of other types of yarn. Lesser the number of jute fibres in yarn cross-section, lesser is the chance of creating disorderliness in the yarn structure after alkali treatment. In this particular blend, the percentage of jute fibres is much less as compared to modacrylic fibre and therefore the alkali treatment does not affect the tenacity of the yarn to a large extent. After alkali treatment, as the jute fibres shrink the major part of the load is shared by the modacrylic fibres during tensile loading upto complete removal of crimp from the jute fibres in the blend. That is why, in 40:60 jute/modacrylic yarn the effect of high extension property of modacrylic fibres is predominant on the extension of blended yarn.

Figs 5 and 6 show that the change in work of rupture (WOR) with the changes in alkali conc. and blend ratio of the yarn follow a similar trend as that of the breaking extension values. Fig. 5 shows that the breaking extension of all the yarns increases with the increase in alkali conc. Since, the work of rupture gives the combined effect of stress and strain, it may be concluded that the change in breaking extension of the yarn plays a dominant role in the change of work of rupture of the alkali-treated yarns.

3.3 Yarn Appearance

It was reported[2, 3] that the alkali treatment changes the natural colour of the jute fibre to brownish. It is also observed that the whiteness and yellowness of 100% jute yarn reduce remarkably on alkali treatment at 18% and 22% concentrations. The darkening of colour of jute by alkali treatment is due to the more exposure of surface lignin upon hemicellulose dissolution and also aerial oxidation of jute lignin [16] in alkaline medium.

The appearance of the untreated yarns in terms of whiteness, yellowness, brightness and gray value improves gradually with the gradual increase in percentage of modacrylic fibre in the yarn. The appearance of 80:20 jute/acrylic yarn deteriorates on alkali treatment. This is due to the presence of comparatively small quantity of modacrylic fibres in the blend which could not off-set the effect of colour change of jute component of the yarn. However, further increase in percentage of modacrylic fibres improves the appearance of blended yarns after treatment. In case of 60:40 and 40:60 jute/modacrylic blends, it is observed that after alkali treatment the whiteness indices of the yarns remain unchanged, moreover the brightness indices and mean gray values increase appreciably (Table 3). It is also observed that the increase in alkali concentration from 18% to 22% does not further improve the appearance of the yarns.The overall improvement in appearance of jute/modacrylic yarns establishes the phenomenon of preferential migration of acrylic fibres towards the yarn surface due to the alkali treatment.

4 Conclusions

4.1 Axial shrinkage of the yarns increases with the increase in alkali conc. up to 18% and then it almost levels off. Alkali-treated 100% jute yarn shows more pronounced weight loss with the increase in concentration of alkali as compared to blended yarns.

4.2 In spite of the marked drop in tenacity there is a substantial increase in breaking elongation and work of rupture of all the yarns after alkali treatment.

4.3 Initial modulii of blended yarns decrease with the increase in the proportion of modacrylic fibres in the blended yarns. With the increase in concentration of alkali, all the yarns show a decreasing trend of initial modulii values.

4.4 Statistical analysis shows that the modulii at different initial strain levels and tenacity are highly correlated with the packing coefficient of the yarns.

4.5 Though the untreated blended yarns show higher bulk than 100% jute yarns, the increase in bulk of blended yarns is not appreciable after the alkali treatment.

4.6 The overall appearance of the blended yarns improves after the alkali treatment with gradual increase in the percentage of modacrylic fibres in the yarn.

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