A Review on Mechanical Properties of Natural Fiber Reinforced Hybrid Polymer Composites

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ABSTRACT:
The natural fiber reinforced composites are being used in various fields of applications that are contributing to the replacement of synthetic fibers composites which consists of Boron, glass fiber, carbon fiber etc.. The composite natural fibers are being used due its light weight, higher specific strength and eco friendly natural, non –abrasive which also have economical value. As they are made out of natural plants they can absorb an considerable amount Carbon dioxide which the surrounding produce. Thus the hybrid composites with different fibre lengths and reinforcements may contribute a better role than those of single fiber composites. This paper provides a review on the mechanical properties (tensile, flexural, impact strength) of natural fiber reinforced hybrid composites.

Keywords: Natural Fibers, Hybrid Composites, Mechanical Properties , Polymer composites .

1. INTRODUCTION

The recent developments in the last 30 years are towards the growth and usage of bio-degradable materials in the field of engineering. The natural fiber hybrid composites are one of those developments that have contributed its essential growth in the field of engineering. Composites are combination of different layered system in which the stacking and layering up contributes the change in properties of the system which are different from its individual nature. They have chemical bonded layer that separates the two or more distinct multi functional materials. There are more than one discontinuous phase bonded to form the hybrid composites which are stronger and stiff which is called as the reinforcement and the continuous phase is termed as matrix phase. These matrix phase materials are classified into different types such as metal matrix, polymer matrix and ceramic matrix. The polymer matrix composites are widely being used in the field of engineering. They are classified into fiber reinforced polymer and particle reinforced polymer. The polymer phase can either be a fibrous or non fibrous (particulates) in nature. The fibers which are processed from chemicals are called synthetic fibers and are classified into glass, carbon, aramid, boron, ceramic fibers and etc. There are different types of fibers that are extracted from different sources of nature such as plants and other living things are called as natural fiber which includes seeds, trunks, bast, fruit etc. The fibers also made from natural sources of biomass products of natural origin chemicals such as(cellulose, hemicellulose, lignin, pectin, wax and moisture , starch) are called natural fiber and it includes the following plant fibers such as, sisal, ramie, coir, banana, agave, snake grass fiber, jute, abaca , pineapple, cotton, flax etc. The main factors which influence the mechanical properties of natural fibers is based on the fibre selection, the matrix selection, the interfacial strength, Fiber dispersion, the manufacturing process selected and the porosity of the fiber which includes the wettablity of fibers and air entrapments. The environment depletion have made the global society interest in the development of new composite materials with addition of more than one reinforcement from the bio degradable resources, such as natural fibers which are at low-cost and environment-friendly alternative for synthetic fibers. These fibers have been extracted by much process like mechanical decorticator, water retting, chemical retting etc. The hybrid fibers composites are able to withstand higher load compared to single-fiber reinforcements which are reinforced in different direction, and the surrounding matrix keeps them in the desired location and orientation, acting as a higher load transfer medium between them. natural fibre polymer composites are fabricated by using traditional manufacturing techniques which are designed for conventional fibre reinforced polymer composites and thermoplastics.**[38]**These techniques include resin transfer moulding (RTM), vacuum infusion, compression moulding, direct extrusion, compounding and injection moulding. The chemical treatments of fibers also influence the characteristics of composites which include treatments such as alkali, acetyl, silane, benzyl, acryl, permanganate, peroxide, isocyanate, titanate, zirconate and acrylonitrile treatments and use of maleated anhydride grafted coupling agent **[39].** The most popular are alkali, acetyl, silane and maleated anhydride grafted coupling agent, but enzyme treatment is becoming increasingly popular with particular benefit relating to environmental friendliness**[40]**.Alkali treatment removes fibre which exposes the cellulose and increases surface roughness/area providing for improved interfacial bonding. Alkali treatment which modifies cellulose structure at high concentration causes the crystalline amorphous nature **[41].** The studies have also reported that due to improvements in interfacial shear strength also improved tensile strength, Young's modulus. The failure strain, impact strength and flexural properties of composites as well as thermal stability and toward reduced moisture content was observed with alkali treated natural fibers that has contributed to a greater impact on the hybrid composites mechanical properties **[42].** The natural fiber matrix selection is polymeric for reinforcements of fibers. The most commonly used polymeric elements which are thermoplastics such as polypropylene and polyethylene. The thermosets which are being used are unsaturated polyester, epoxy resin, phenol, and formaldehyde and VE resins.**[43]**But it has been found out that use of the polylactic acid has shown a better provider for stiffness and higher strength to fibers rather than poly propylene. The other commonly used resin is the epoxy which is capable of high adhesive strength and stiffness property in the mechanical properties of hybrid polymer composites. This paper details and presents the research on the various combinations and mechanical properties of natural fiber hybrid composites.

2. LITERATURE REVIEW ON MECHANICAL PROPERTIES

Jawaid M et al **[3]** has evaluated the tensile properties of oil palm empty fruit branches (EFB) and jute fibre reinforced polymer composites. There were two types of a skin and a core material placed in a tri layer composite form. The oil palm fiber and jute fibers are chopped off and mats of layers are stacked with relative weight ratio of 4:1 and are coated with the epoxy resin and polyamide mixed with diluter. It is found that the stacking of jute as skin over palm fiber has made the composite to with stand higher load due to the higher strength of jute , but they had lower strength than jute due to the high porosity or the presence of voids on the surface of pure EFB composite. When voids were presents, it causes air on the surface or inside to be trapped which would cause high porosity of oil palm EFB fibers.**[4].**

Table : 1 Tensile strength and tensile modulus of EFB/Jute/EFB and Jute/EFB/Jute fibre reinforced hybrid composites.

Samples	**Tensile Strength (Mpa)**	**Tensile Modulus (Gpa)**
Epoxy	20.60	1.98
Pure EFB	22.61	2.23
Pure Jute	45.55	3.89
EFB/Jute/EFB	25.53	2.39
Jute/EFB/Jute	27.41	2.59

Idicula et al **[5]** has done about study on sisal and banana hybrid composites and has reported that the mechanical properties such as tensile flexural and impact properties of short sisal / banana hybrid fiber reinforced composites. The polyester resin with curing agents methyl ethyl ketone peroxide and catalyst cobalt naphthenate where the resins had the following characteristics of tensile strength 33Mpa, Flexural Strength 70 Mpa, and Impact strength 9kJ/m^2. The surface area of banana fiber is higher than sisal because of the diameter of banana fiber is less than that of sisal. After the loading of composites the results showed that there was higher tensile strength shown when the volume of both banana and sisal increased volume ratio of banana and sisal 3: 1.Tensile and flexural properties has shown a positive hybrid effect, while impact performance showed a negative hybrid effect. When the Vf of sisal is 0.26, the maximum modulus is obtained. The volume fraction at 0.40 and volume ratio of banana and sisal at 1: 1. Flexural and impact properties were higher in bilayer composites. Tensile strength was maximum in banana/sisal/banana composite.

Table 2: Mechanical Properties of composites having different layering patterns of fibers (total V_t=0.4 ,banana : sisal =1:1)

Properties	**S/B**	**S/B/S**	**B/S/B**
Tensile strength (Mpa)	54	54	58
TensileModulus (Mpa)	1302	1290	1476
Elongation Of Break	6	6.2	5.4
FlexuralStrength(Mpa)	65	61	63
Flexural Modulus(Mpa)	2991	2846	2916
ImpactStrength(kJ/m^2)	43	37	36

Venkata Reddy al **[6]** has investigated the compression properties of Kapok / sisal reinforced polyester composites. The fibers were 2% alkali treated.. When addition of about 25wt% sisal fiber to kapok reinforced composite increases its compression strength by 14.8% and adding of sisal fiber to 75wt% increases the compression strength to 72.5%. The non alkali treated kapok fabric composite is decreased by 111.7 and 96.5% for 5 vol. % total fabric content from the unreinforced matrix. This is due to weak interfacial adhesion between fiber and matrix. There is a positive hybrid effect has been found at 1 : 1 (50 : 50) and 1 : 3 (25 : 75) volume ratios of kapok and sisal because of the good adhesion between fabrics and matrix.

Table 3: Compression Strength Of Sisal / Kapok hybrid composite Fibers-Total fabrics content (vol5%)

Kapok-Sisal volume (%)	**Compressive strength (Mpa)**	
	Untreated	**Treated**
100-0	65.3	78.3
75-25	75.0	84.1
50-50	102.5	111.6
25-75	112.7	121.3
0-100	130.1	156.6
matrix	153.9	153.9

Noorunnisa Khanam P et al **[7]** has prepared a Sisal/silk fiber reinforced unsaturated polyester composite which consists of different fiber lengths and tensile, compressive and flexural tests were conducted. The sisal fibers were dipped in 2% NaOH for 1hr, cleaned after dried at 70^0C for 3hrs. Then the chopped fibers are then treated with resins of unsaturated polyester and styrene which are mixed at 100:25 parts. It was found that the 2 cm fiber had higher tensile property of about 24.5% higher than untreated fibers. Also the Flexural and compressive strength were also 18.5% and 35.6% higher than untreated composites.

Sathishkumar et al **[8]** has analyzed the tri layered snake grass reinforced polyester composites with banana and coir fiber. The results concluded a a maximum tensile and flexural strength was wielded in 20%V_f of SG/B fibers and 25% V_f of SG/C composites and SG/B The tensile strength for the SG/B is higher than the SG/C fiber-reinforced composites. Thus it concludes that volume fraction of fibers play a major role in the impact of mechanical properties.

Maya Jackob et al **[9]** has investigated the function of fiber loading, ratio and treatment in sisal /oil palm reinforced with rubber composites. When there was the addition of sisal and oil palm fibers there was increase in the tensile strength and tensile modulus of composites and properties also increased when alkali treated. There was an increased mechanical strength when the fibers were arranged in longitudinal direction rather than in traverse direction. The value of elongation at break reduces with increased fiber loading. Due to increase in fiber loading the fibers become strong and stiff and reduce resilience and toughness which leads to lower elongation at break.

Libo Yan et al **[10]** has investigated the mechanical properties of the natural fibers of flax, linen and bamboo composites under alkali treatment. The main purpose of alkali solution treatment is increasing the surface roughness due to the disruption in H bonding. This treatment removes a certain amount of lignin, wax and oils covering the external surface of the fibre and increases the degree of polymeristion [**12]**. The reaction follows in this order to any fabric as**[13]**

$$\text{Fibre - OH + NaOH ® Fibre = } O^{-}Na^{+} + H2O\ .$$

The fiber containing hydroxyl groups are more compatible with epoxy resins. The three point bending tests, tensile test were done. The results concluded that alkali treatment increases the tensile strength and modulus of composite. According to **Ghosh** et al **[11]**, the tensile failure of viscose fibre yarn is strongly dependent on the yarn structure, i.e. the configuration, alignment and packing of constituent fibers in the yarn cross section For fabric with loose packing of fibers in the yarns, the yarn failure mechanism is slippage dominated, thus the load-bearing capacity of the slipped fibre is reduces.

Sathishkumar et al **[14]** has evaluated the characteristics of the sisal / fiber cotton fiber reinforced composites. The tensile strength, flexural strength and impact strength and tensile modulus of these composites were maximum at 40% V_f fibre in both directions. This is due to the cohesion of the forces exerted between adjacent matrixes. In the testing phase of tensile properties there was shear off of sisal fibers out of the composites than the cotton fibers.The layering pattern mainly plays an important role in the mechanical properties of composites.

Table 4: Mechanical Properties of Hybrid Polyester Composites

Fibre Volume Fraction (%)	Fiber Direction	Tensile Strength(Mpa)	Flexural Strength (Mpa)
10	S	30.22	74.59
10	C	24.5	60.61
40	S	63.55	270.4
40	C	53.45	237.61
50	S	42.45	230.45
50	C	36.45	186.5

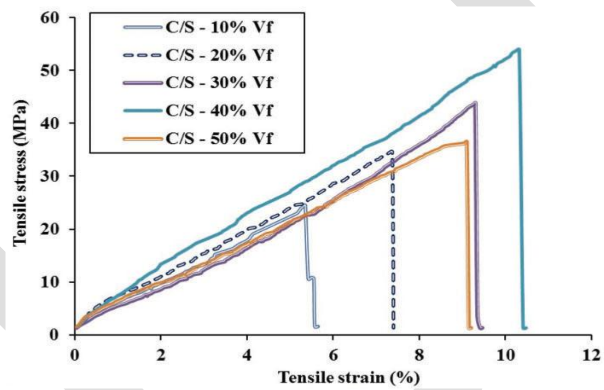

Fig 2: Tensile properties of Cotton / Sisal Fibre Composites

Wang et al. **[15]** proposed that the impact properties of 3D woven basalt/aramid hybrid composites. The interply hybrid composite showed highest ductile, lowest peak load, and highest specific energy absorption than intraply hybrid composite. The interplay composites showed larger energy absorption while the intraply composites showed the lesser energy absorption in layer by layer composite stacking.

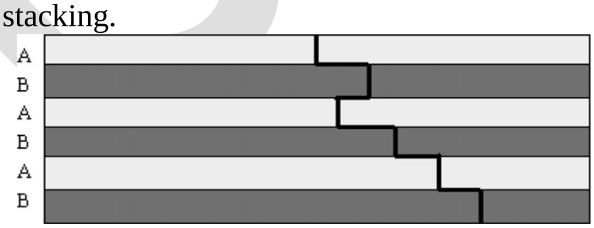

Fig 1: Crack propagation path of interply composite in low velocity impact

Venkateswaran N et al **[16]** has evaluated the mechanical behavior of the banana/sisal fibre composites. In comparing the banana epoxy fiber composites it has found that the optimum length was 15 mm and weight percentage was 16%. When the banana fiber is compared to banana/sisal hybrid composite reinforced with epoxy resin there was an increase of about 16 % , 4% , 35% in tensile , flexural and impact strength of the composite under same length and weight percentage. There is small increase due to weak interface and improved by alkali treatment.

Table 5: Tensile, Flexural and impact properties of hybrid composites

Fiber content banana/sisal	Tensile strength (Mpa)	Flexural Strength (Mpa)	Impact Strength kJ/m^2
100/0	16.12	57.33	13.25
75/25	17.39	58.5085	15.57
50/50	18.66	59.687	17.9
25/75	19.93	60.8655	20.22
0/100	21.2	62.044	22.54

Surendra et al **[17]** has investigated the mechanical properties of sisal jute and okra natural fiber reinforced polymer composites. The fibers were prepared from 35 % sisal, 35 % jute and 30 % okra which are been kept in varying weight ratios of 0.4-2grams.The composite was molded out and test specimen was taken out. The results showed that the tensile strength of hybrid (sisal + jute + okra fiber) reinforced polymer composite is 9.8% higher than that of sisal fiber reinforced polymer composite and the tensile modulus of hybrid reinforced polymer composite was 8.7% higher than that of sisal fiber reinforced polymer composite. The maximum flexural strength of reinforced polymer composite was 4.7% higher than that of sisal fiber reinforced polymer composite. The maximum impact energy of hybrid reinforced polymer composite is 33.6% higher than that of sisal fiber reinforced polymer composite.

Athijayamania A et al **[18]** has investigated the effect of moisture content on the roselle sisal fiber reinforced polyester hybrid composites.. It was found that the highest flexural strength was found at 150mm fiber length of 30% weight content of fiber and maximum impact strength was found at 150mm fiber length of 20% weight content of fiber for the dry condition than the wet condition. There was also improvement in tensile property due to increase in fiber length and content in dry condition rather than in wet condition. The decrement is due to weak interbonding.

Noorunnisa Khanam et al **[19]** has experimented on the randomly oriented coir/ silk fiber reinforced unsaturated polyester composites. The coir fibers were treated with NaOH 2% concentration for 1h. Then the resin with styrene in 100:25 parts. It is observed that the tensile, flexural and compressive properties of randomly oriented coir/silk fiber hybrid at 2 cm fiber length composites have higher properties than others fiber composites. The difference in properties was also due to the alkali and non treatment nature. Alkali treatment improves the adhesion between the coir fiber surface and matrix by removing hemi cellulose and lignin from the fiber. The corresponding property values are listed in the Table 6**.**

Thiruchitrambalam et al **[20]** investigated the woven mat of banana/kenaf fiber polyester based reinforced hybrid composite. It is prepared with 10% alkaline and 10 % sodium laulryl sulphate-treated fibers.The maximum tensile and flexural strength was found at 40% volume fraction of woven hybrid fiber composites. It is found that the sodium lauryl sulfate gives higher property value than alkali treatment

Table 6: Coir /Silk Hybrid Composites Properties between Treated and Untreated Fibers of Different Fiber Length

Fiber length (cm)	Tensile strength (Mpa)		Flexural Strength (Mpa)		Compressive strength (Mpa)	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
1	11.419	15.014	37.419	39.533	134.895	154.034
2	15.624	17.24	43.744	45.067	142.087	162.975
3	12.924	16.144	39.692	42.018	138.401	159.822

Vikas Sahu et al **[21]** has investigated the mechanical properties of sisal and pineapple fiber reinforced composites with epoxy resin.It showed that the tensile property of hybrid composite was higher than pine leaf but lesser than the sisal fiber. The impact strength of hybrid was higher than sisal fiber. The hybrid composite made with 50:50 ratio of pine and sisal showed good performance.

Rosni Binti Yusoff et al **[22]** has investigated the tensile and flexural properties hybrid green composites by using kenaf, bamboo and coir fibers to reinforce polylactic acid (PLA) polymer matrix. The results obtained showed that there was the Kenaf bamboo coir /PLA composites achieved 187 MPa Tensile strength which is 20% and 78% higher than bamboo-coir/PLA and kenaf-coir/PLA, respectively. Higher youngs moduli is shown by kenaf and bamboo fibers which contribute higher resistance loads at outer layers with high stiffness while coir fibers show ductile properties **[23]** .When the coir fiber content was high (more than 25%) in other composites where low coir content resulted in low toughness which displayed high elastic modulus that are used for structural applications **[24]**. High flexural strength was shown by the kenaf-bamboo-coir/PLA (199 MPa) and bamboo-coir/PLA (206 MPa) composites which are 16 % and 20% higher than that of kenaf-coir/PLA. But the kenaf-coir/PLA composites had the highest flexural modulus which is 70% higher than other composites.

Vijaya Ramnath et al **[25]** has investigated the mechanical properties of abaca –jute with glass fiber reinforcement. The abaca and jute fibers are arranged in horizontal and vertical orientation in which the resin is applied in each layer. It is found that jute fiber in reinforcement increases strength. It was found that the stacking sequence is more important than composition in determining impact toughness **[26]**.Resin toughness rather than fiber strength and stiffness is the major parameter including the impact strength of the composite **[27]** The abaca individual fibre has high impact strength because of variable directional single type fibre. When crack propagates in a fiber due to directional changes when it reaches the end it travels to next layer which acts in different direction.

Vasanta V Cholachagudda et al **[28]** has proposed that coir and rice husk hybrid reinforcement. There is an increase in the flexural strength of the composite increases but decrease at 5% wt of Rice Husk fiber loading. When addition of Coir to the Vinyl ester the tensile strength increases by 27.80% at 15% fiber loading and decrease at 20% wt of coir loading by 20.85%. In hybrid composite the rice husk is added at optimum point it increase the tensile strength by further 7.64%.The flexural coir composite increases by 39.40 at 15% coir loading and 43.84% at 20% coir loading. The flexural strength increase further by 9.78% at 1% Rice Husk, 10.74% at 3% Rice Husk, 6.02% at 5% Rice Husk addition this means addition of Rice Husk more than 3% results decrease of flexural strength hence hybridization more than 3% wt fiber loading reduces the flexural property.

Libo Yan et al **[29]** has investigated the tensile strengths of flax and linen fabric reinforced composites increased 64.5% and 44.1%, respectively, compared to pure epoxy (73 MPa). The tensile moduli of flax and linen fabric reinforced composites are 157.1% and 97.1% higher than that of pure epoxy (3.5 GPa), respectively this indicates that the addition of fabrics increases the tensile strength and modulus of the composites because a uniform stress distribution from the epoxy is transferred to the unidirectional fibre.

Czigany T [1] have characterized and discussed about the mechanical properties and characteristics of reinforcement of basalt fiber and its composites. The base of basalt fiber is basalt rock, which is an over-ground, effusive volcanic rock saturated with 45-52% SiO_2 **[2]**. The fibers were surface treated with sunflower oil and maleic anhydride which improves the reinforcement property of fibers.. The hemp fiber and glass fiber reinforcements showed less anisotropic property compared to glass and carbon fiber reinforcement. The fibers after carded were obtained from the industrial hemp plant and the average HF diameter was 50.6-16.9 mm.. The composites were produced by using a hot pressing technique. The Multi cylinder carding machine was used for achieving the homogeneous distribution of fibers.. A multi layered material was formed. This caused a drawback of reduction in length. The multilayered mats of composites were produced from hot pressing The mechanical property of the It verified the testing of basalt fibers being an excellent substitutive in reinforcement in carbon fibers composites. This also shows that the hybridization of hemp and basalt fibers showed less progress.

Murali Mohan et al **[30]** has investigated the Vakka fiber composites with respect to the other fibers such as the bamboo, sisal and banana fibers.. The tensile strength of vakka fiber increases at a 0.37 volume fraction is 32% and 8% more than that of sisal and banana fiber. .It was found that the vakka fibers exhibited greater tensile strength and flexural modulus than sisal fibers. Thus in this composite when there is an increase in volumetric fraction increases the mechanical property of the substance. This also has special characteristics of dielectric strength which increase with volumetric fraction.

Jamal Mirbagheri et al **[31]** has evaluated the tensile properties of the wood flour kenaf hybrid polypropylene composites. Maleic anhydride and dicumyl peroxide were used as the coupling agent and initiator. The long kenaf fibers when added, increases the properties of composites with a wood flour fiber. When 10% of kenaf fibers are added the tensile properties of composite materials are obtained.

Boopalan et al **[32]** has investigated the mechanical properties of jute and banana fiber reinforced epoxy fiber composites. The maximum values which are obtained for tensile strength, flexural strength and impact strength are 18.96 MPa, 59.82 MPa and 18.23 kJ/m2. When the reinforcement was in 50/50 volumetric weight the tensile, flexural and impact strength was maximum. When the addition of banana fiber results in 17% increase in tensile strength, 4.3 % increase in flexural and 35.5 % increase in impact strength. There is less number of voids which shows the presence of fiber-polymer matrix interaction with composite material.

Table 7: Mechanical Properties of Jute/Banana Composite Material.

Weight ratio of jute /banana	Tensile Strength (Mpa)	Flexural Strength (Mpa)	Impact Strength (kJ/m^2)
100/0	16.62	57.22	13.44
75/25	17.89	58.6	15.81
50/50	18.96	59.84	18.23
25/75	18.25	59.3	17.89
0/100	17.92	58.06	16.92

3. APPLICATION

The natural fibre reinforced composites are being used in the various fields of applications of day to day life which are being specifically used to accommodate lesser cost and lighter materials. The composites were used in the were used for many automotive, structural, construction, common storage devices etc. In the field of automobile engineering they used in the sound engineering control which is the Noise vibration Damping **[34]**. They are used in as floor area for sports utility vehicles. They are used in door claddings seat back lining and floor planning **[33]**. The flame redundancy is achieved by the thermosets and thermoplastic polymers textile composites **[35].** They are used in daily usage applications of lampshades, plates, spoons etc. In

India composite board has been developed as an alternative to medium density fibre board which has been assessed for use in railcars. They used in package containers, visors , instrument panel , engine covers , racks. The aircraft industry is adapting the natural fiber hybrid composites for interior panels **[36]**. They have also being used in biomedical applications as sutures in wound dressing **[37].**

4. CONCLUSION

The mechanical properties of various combinations of natural fibers hybrid composites were studied and some features were discussed.

1. The mechanical , flexural and impact strength of different hybrid fibers were studied
2. When there was hybridization of two different fibers the resulting depends on the reinforcement of the fibrous matrix.
3. The impact strength of the fibers depends on the matrix reinforcement interface bonding rather than the fiber matrix adhesion.
4. The mixing of natural fibers with other natural fibers enables low cost of production and less weight.
5. The volume fraction or weight fraction and fiber length must be optimized to ensure maximum performance.
6. The fibers were also compared between chemically treated and untreated fibers used in the hybrid Composites.

Hence the natural fiber reinforced hybrid polymer has been used to replace the synthetic fibers reinforced polymer composites. But entire replacement of the future with hybrid composites is sufficiently low due to its huge difference in properties as compared to synthetic fibers . For improving the composites properties, the fibers can treated with various chemicals and matrix blend .Thus the significant improvement in the properties can result in replacement of synthetic fibers with natural fibers in heavy load applications.

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