Wear Resistance and Wear Pressure of Natural Reinforced Composites

Nwigbo S.C., Onyeanusi C.F.

ABSTRACT

This paper provides the results of wear resistance, wear pressure as well as the wear track of natural reinforced composites. The dicotyledonous composite produced from castor oil beans seed shell and oil beans seed shells were tested. The wear rates were compared to determine optimal wear resistance. To evaluate wear resistance of the materials, the dry wear tests were then performed using a pin-on-disk test rig under different operating conditions. The results show that the volume losses predicted by the numerical analysis are in good agreement with the experimental data. The results showed that castor oil bean seed shell composite reached the maximum wear resistance at wear pressure of 3N against the oil bean seed shell and pure polythene composites. At an average speed of 130 rpm, 2N load, under dry condition the wear track was simulated. The state of wear scar on the plane was a condition established along the mean diameter of the scar away from the contact point using the COSMOSxpress.

Keywords: *Wear, Wear rate, Wear Resistance, Wear Pressure, Wear Track, Composite, Pin–on-disk*

1. INTRODUCTION

The wear resistance of an engineering material depends largely on the sliding speed, load, temperature of the material, volume loss as well as type of lubricant. The wear resistance of materials is defined as a standard specification of materials during testing with special laboratory machines that simulate the real processes of wear.

Lubricants serve as an interfacing material to reduce frictional or adhesive wear, remove impurities, reduce temperature and increase production efficiency Nwigbo S.C. et al (2010). Lubricant reduces the wear rate and increases wear resistance of a material.

The resistance of materials to wear entails its wear resistance ability. The wear resistance of the materials was evaluated in Pin on disk using ASME G99 code. If one of the surfaces which are in touch is rough and hard, it chips the other surface due to relative motion or touching forces.

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The wear is called two-body abrasive wear. If there are free abrasive particles between the two bodies, the wear is called three-body abrasive wear. The free abrasive particles may be external material dust or the remains of chipping Lee, S.W. et al. (1993). The wear behavior of silicon nitride, for example, in dry air exhibits both speed and load dependence with a low-wear region in the form of a valley. Wear transitions can be observed on both the speed and load axes when a critical load and a critical speed are reached Nosonovsky, M. & Bhushan, B. (2007).

the abrasive wear resistances of heat-treated steels were found to be different than that of non-heat treated steels. Researchers concluded that this difference was due to the heat-treatment of the material. After heat-treatment the hardness of the material changes, its wear property changes. Khruschov, M., M.(1974) noticed that the wear resistances of non-heat-treated and heat-treated steels are dependent on abrasive particle size. However, Misra and Finnie (1981), have found that the shape-changing rate has only changed the wear resistance, and has no effect on the dependency of abrasive particle size.

Usually, the wear starts as a two-body abrasive or adhesive wear and then becomes a three body wear as dust form

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between the two surfaces due to external particles, chipping remains, or oxide particles.

According to Zhang et al., the wear resistance of compact graphite irons is greater than the wear resistance of gray and ductile irons, independent of contact pressure or sliding speed. This is due to an excellent combination between high mechanical resistance and good heat-transfer capacity.

2. EXPERIMENTAL DETAILS

2.1 Materials

The wear resistance of natural reinforced composite was used in this work. The nominal

Composition of the reinforcement was 30% for sample the natural composite. Two different micro particles from dicotyledonous plants were used as a reinforced material.

Particles from castor oil seed shell and oil beans seed shell was used as composite reinforcement. Nwigbo S.C and Onyeanusi C.F (2016) determined the coefficient of friction, heat generation as well as the morphological analysis on the materials. As shown in Table I, some of the properties of the material as show below.

Table 1. The Contact Conditions of the laboratory tests.

Material	Composition by wt(%)	Flat face Measurement (mm)	Coefficient of friction
Castor oil bean Seed Shell	30	12.0 by 5.50	0.0004
Oil bean Seed shell	30	8.24 by 3.65	0.00002
Pure Polythene	-	12.69 by 3.08	0.0000246

2.2 Wear Test / Procedures.

The tests of abrasive wear were conducted in accordance to procedure of standard ASTM G99 - Standard Test Method for wear testing using a pin on disk Apparatus. The abrasive wear behavior of the dicotyledonous reinforced composites was studied using a pin-on-disc abrasive wear tester. For abrasive wear tests, wear pins on the flat faced surface were held against rotating disk. The abrasive wear is found to increase with the increase in normal load and sliding rates.

The abrasives are introduced between the test specimen and the rotating wheel. The test specimen was pressed against the rotating wheel at a specified force by means of lever arm. The rotation of wheel was such that its contact face was 75mm radius moves in the direction of grit flow. This radius forms the radius of the wear track on the disk. The pivot axis of the lever arm lies within a plane. Which was approximately tangential to the wheel surface, normal to the horizontal diameter along which the load was applied. Start the motor and adjust the speed to the desired value while holding the pin specimen out of contact with the disk. Stop the motor. Set the revolution counter (or equivalent) to the desired number of revolutions.

The tests were carried out for different loads, no of revolutions, speeds, time taken as well as sliding distances.

2.3 Experimental Assumptions

The following experimental assumption was adopted in the work

1) The pinned surface is assumed to be constant. That is, the thickness and the width of specimens are the same.
2) The specimen on the disk is fixed perpendicular to the axis of the resolution.
3) It's assumed that there is no loss of heat from the disk to the atmosphere even absorption of heat by the disk.
4) It's also assumed that the speed of the system does not changed when loaded at different masses.
5) That, the abrasives are introduced between the test specimen and the rotating wheel maintained a manufacturer specification hardness of P80.
6) Unnecessary vibrations are developed on the system lever by force pressing the pin against the disk.

2.4 Test Conditions

During the tests, the temperature was 29 ± 2°C and the relative humidity was 79 ± 3%. Two individual tests were made for each material combination.

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The whole system, including the pin-on-disk machine, was tested by starting all components simultaneously without any contact between the pin and disk. Wear testing started after the concentration had reached zero.

Table 2: The Contact Conditions of the Laboratory Tests.

Specimen/ Disk material	Load (N)	Time (Sec)	No of Revolution	Sliding Velocity (RPM)
Castor oil seed Shell Composite/ 80P Emery Paper	1	13	30	120
	2	28	60	130
	3	40	90	135
Oil Bean Seed Shell Composite/80P Emery Paper	1	13	30	120
	2	28	60	130
	3	40	90	135
Pure Polythene/80P Emery Paper	1	13	30	120
	2	28	60	130
	3	40	90	135

Emery abrasive paper of P80 grit size was used as an abrasive medium. The abrasive wear test of the composites was conducted under normal load, sliding speed, sliding time as shown in table 2.

3. Results and Discussion

Wear resistance is a term frequently used to describe the anti-wear properties of a material. However, the scientific meaning of wear resistance is vague, and there is no specific unit to describe wear resistance.

Nevertheless, the inverse of mass loss or volume loss is sometimes used as the (relative) wear resistance. The ratio of wear loss for a reference material over that of the investigated material under same testing conditions can also used as relative wear resistance.

The mass of the sample were determined gravimetrically and recorded. The wear volumes, V, were determined from the measured mass losses using the specific mass of the samples. The linear wear rates, W, were computed using the following equation

$$W = \frac{V}{LA} \quad (1)$$

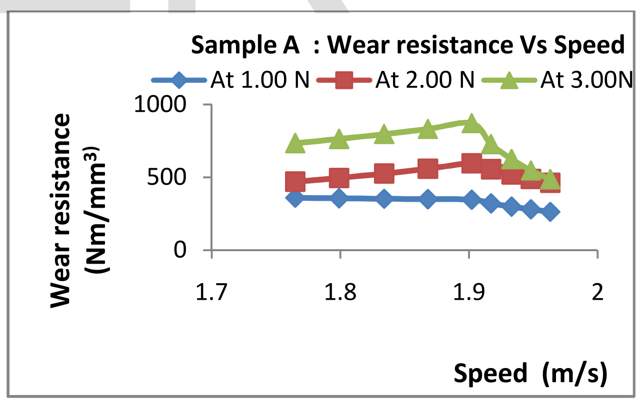
where L is the sliding distance of the experiment sample and A is the wear surface area of the sample.

The abrasive wear expressions and definitions given in nomenclature section. In particular, we define the pressure wear resistance, W_p^{-1} as:

$$W_p^{-1} = \frac{P}{W} \quad (2)$$

where P is the applied pressure to the experiment sample, and W is the linear wear rate defined.

There is a linear relationship between the abrasive wear resistance W^{-1} and hardness H depending on abrasive particle size d. The relationship between wear coefficient k and abrasive particle size d is a parabolic as seen in equation. The wear resistance W^{-1} is inversely proportional with the square root of particle size d, for non-heat treated steels as seen in equation Sevim .I.(2013),



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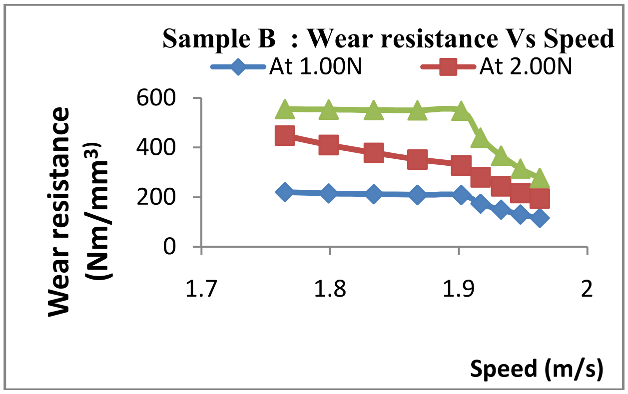

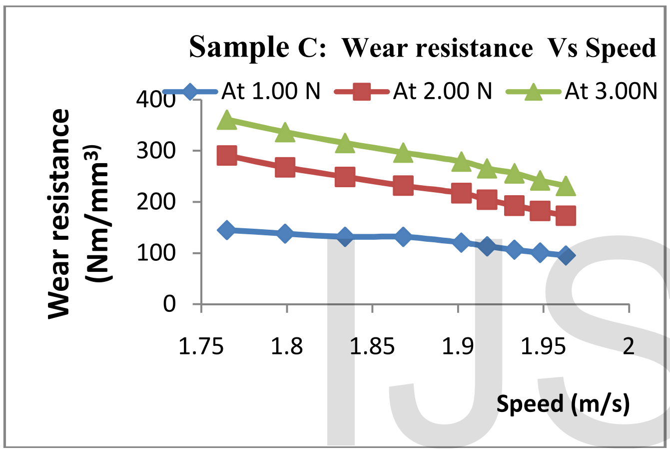

Fig 1: *Graph of Wear resistance against speed. Where Sample A, B and C are Castor Oil Seed shell reinforced composite, Oil beans Seed Shell reinforced Composites and pure Polythene Composite respectively*

The normalized Castor oil seed shell composites shows a resistance to wear which is higher than the oil bean seed shell composite. While the pure polythene shows a relatively poor resistance to wear. The similarities in the result of the natural composites are obvious at 3N but changes as the wear pressure decreases.

Generally, it is true that the harder the material, the better is its wear resistance. In the reported in this paper, the Castor oil seed shell composite showed a greater wear resistance than the oil bean seed shell composites. This is in accordance with results reported by Lehman.(1927) In making wear tests on cast iron he found that the main factor which governed the resistance to wear of cast iron was the percentage and size of micro particles. Meaning that the micro particle size of the castor oil bean seed shell are bigger in the matrix.

Fig 2: Comparing the wear rate and wear resistances of the composite

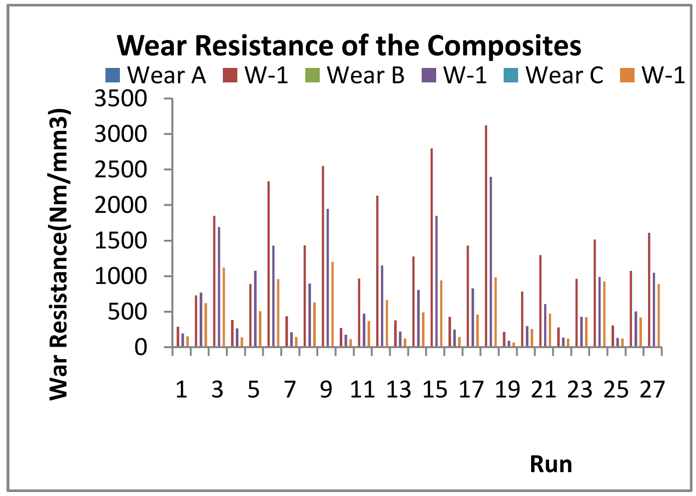

Fig 2: Histogram of the wear resistance per wear test.

Since these samples showed the wear resistance was maximum at 3N wear pressure in all the samples. The histogram demonstrates that the wear-resistance of castor oil beans seed shell specimens with 30wt% compositions particles is higher than that of oil beans specimens with the same micro particle contents.

3.2 Stress-Displacement on the disc

A rotating disk develops substantial inertia-caused stresses at high speeds. The tangential and radial stresses in a disk rotating at ω rad/sec. These rotating disks, on which the specimens rubs are usually rotating with high angular speed.

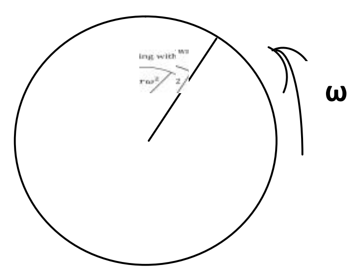

Fig 3: Wear Rotating disk

High angular speed leads to formation of centrifugal force in disks and this phenomenon eventually causes deformation and radial displacement in rotary disk (Venkatarama Reddy and Hamid EkhteraeiToussi, 2012).

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The accelerations of the disk lead to an inertial force (per unit volume) which in turn leads to stresses in the disc. By correlation of centrifugal force, density of disk material and angular speed, created body force in radial or tangential direction

$$F_r = -\rho r\omega^2 \quad (3)$$

Also, considering , stress-strain equations in polar coordinates have been presented in Equations where σ_r, ε_r, σ_θ, ε_a, E and υ are radial stress and strain, circumferential stress and strain, Young's modulus and Poisson's ratio, respectively.

$$\sigma_r = \frac{E}{1-V^2}(\varepsilon_r + V\varepsilon_\theta) \quad (4)$$

$$\sigma_\theta = \frac{E}{1-V^2}(\varepsilon_\theta + V\varepsilon_r) \quad (5)$$

By considering of problem, equilibrium equations will be simplified to Equation 4.

$$\frac{1\sigma_r}{dr} + \frac{\sigma_r - \sigma_\theta}{r} = -\rho r\omega^2 \quad (6)$$

Subst Equ 4 and 5 into 6

Thus the rotating disk has been converted into an equivalent static problem of a disc subjected to a known body force. Using the strain-displacement relations. and the plane stress then leads to the differential equation

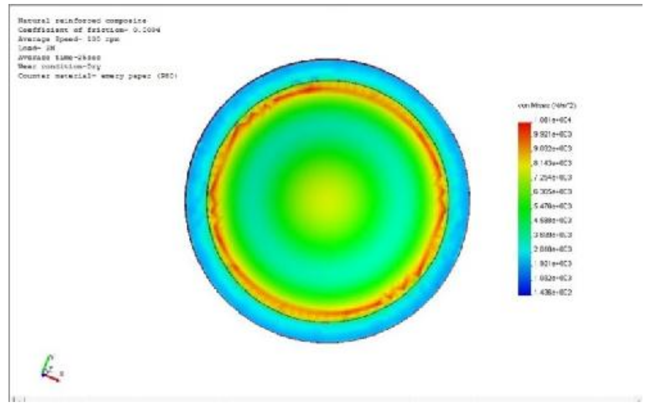
$$r\frac{(\epsilon_r + v\epsilon_r)}{dr} + (1 - v\varepsilon_r)(\varepsilon_r + \varepsilon_\theta) = -\frac{(1-v^2)}{r}\rho r^2\omega^2 \quad (7)$$

Von Mises stress is widely used by designers to check whether their design will withstand a given load condition. According to Kurowski, P.M (2012), Von Mises stress, also known as Huber stress, is a measure that accounts for all six stresses Components of a general 3-D state of stress. Von Mises stress σ, can be expressed either by six stress components as;

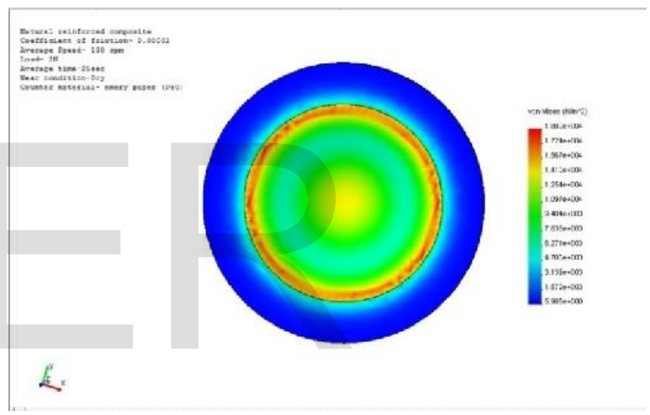
$$\sigma = \sqrt{0.5[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2} + \sqrt{3(\tau_{xy}{}^2 + \tau_{yz}{}^2 + \tau_{zx}{}^2} \quad (8)$$

COSMOSxpress is a design analysis system fully integrated with SolidWorks. COSMOSxpress provides one screen solution for stress, frequency, buckling, thermal, and optimization analyses.

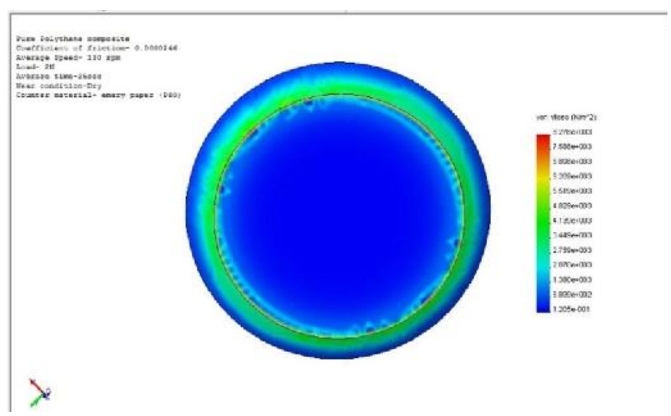
The sigmas (σ) correspond to normal stress values, and the taus (τ) are the shear stress values. COSMOSxpress displays the wear track simulation for the experimental results. Wear scar on the Castor oil beans seed shell against 80P emery paper after the wear tests were studied.



Sample A



Sample B



Sample C

Fig 4: COSMOXSpress of the Stress/Strain displacement on the disk

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In comparison, the castor oil composite test exhibits greater wear deformation at $1.08x10^4 N/m^2$ against the oil bean composite where its $1.88x10^4 N/m^2$. Wear scar with a volume loss of 1.510 mm3. This is results to the formation of a large amount of abrasive debris removed from the Composites during the wear test. These in turn substantially increased the wear rate of both the composites and the emery paper.

As a consequence, a wide and rough wear track was quickly generated. This finding demonstrates the significant enhancement of wear resistance by the samples compared to the counter material. The result showed that the wear resistance is dependent of the grit size of the counter material. The formation of abrasive debris plays an important role in the wear behavior of both the test sample and the counter mat

3.2 Micro-Structural Results

Microscopic examination defines structure of tested materials. Examinations do not indicate internal defects but the internal structure of the specimens.

Scanning Electron Microscopy SEM uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. In most SEM microscopy applications, data are collected over a selected area of the surface of the sample and a two-dimensional image is generated that displays spatial variations in properties including chemical characterization, texture and orientation of materials.

SEM services include Fixation and dehydration, determination of critical point, Image processing etc

Here, the results are limited to the morphological structure of the materials: castor oil seed shell composite and oil bean seed shell composite. With the Pure polythene Composite as a control results, since it does not contain reinforcement.

Typically, samples which are a biological specimen prepared chemically with other reagents, dehydrated through an acetone or ethanol series and then dried at the critical point. This method was used to minimize distortion due to drying tensions. The operating environment of a standard scanning electron microscope dictates that specialist preparation techniques are used

For dry samples, this process is not necessary.

(a)

(b)

(c)

Fig 5: Wear Particles

A: Castor Oil bean seed shell reinforced composite at 30% wt composition

B: Oil bean seed shell reinforced composite at 30% wt Composition

C: Pure Polythene Composite

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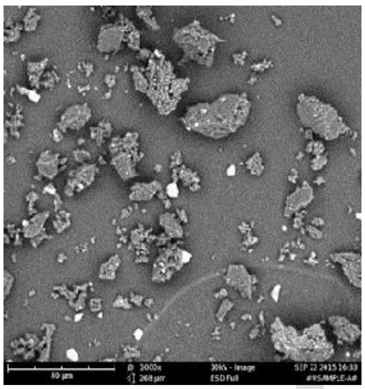
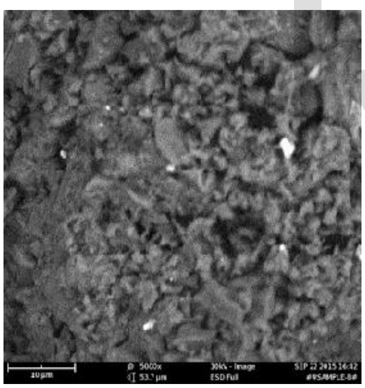
The analysis begins by collecting the wear particles or debris. Application of lubricant or excess heat during the wear can affect metallurgical composition. Particles such as fibers, corrosive wear, sand, dirt, and other elements are identified. The micro structural results depend on the types of particles, the quantities, and their respective sizes of the samples. Detailed photographic images of scanning electron microscopy were done.



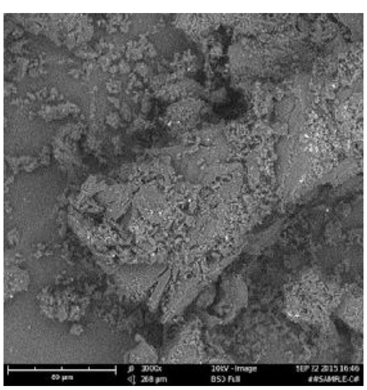
Specimen (a):

Morphology of Particles generated from Castor Oil Bean Seed Shell Reinforced Composite at 30% Composition.



Specimen (b):

Morphology of Particles generated from Oil Bean Seed Shell Reinforced Composite at 30% Composition.



Specimen (c):

Morphology of Particles generated from Pure Polythene Composite

Fig 6: SEM Results of the Composites

Sample A exposes the fibrous structure and flaky arrangement of the particles matrix. It is not a closely parked structure. The white patches are as a result of the inclusion of paper particles. There was an increase in this inclusion as a result of the wear track. Their results will also be used as references when evaluating the resulting SEM images of same composite at different speed. As the speed increases the particle shows.

The dicotyledonous composite shows the structure grain growth of the castor oil and oil bean. This fine structure affects the coefficient of friction and the particulate generated, they seem somewhat disassociated from one another and do not form a complete network of associations. Additionally, the surface topography of the castor oil reinforced composite seems similar to that of the Oil bean reinforced composite. Although not as pronounced, the associations have almost a wave-like structure, loosely connected and flat to dominate the majority of the image.

CONCLUSION

A comparative study was carried out for wear, wear resistance and wear stress of three different types of composite reinforced with a weight contents of micro particles of *30% wt* in composition.

1. Experimental results are obtained for the relationships of wear rate, wear resistance as well as wear pressure on the disk.
2. The relative wear resistance and hardness related linearly abrasive particle size does not affect the relationship between hardness *H* and relative wear resistance. But, the result showed that the wear resistance is dependent of the grit size of the counter material.
3. The wear track under Von Mises Stress showed that the tensile stresses between Pin and Disk material. This starts when both materials are in sliding contact, With von mises decreases from the point of contact
4. Shows that the wear data among the two composites are close, but the pure polyethene composite data fall farther away from the others. This may be caused by the absent of reinforcer or tribochemical reaction.

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