Tribo-Mechanical Evaluation of Epoxy/Periwinkle Particulate Composites

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Abstract: The tribo-mechanical evaluation of epoxy/periwinkle particulate composites was investigated. Periwinkle shell particles were used as reinforcement in the epoxy matrix. 3 to 9wt% periwinkle particles at intervals of 3wt% were added to the epoxy as reinforcement. Themicrostructural examination of the epoxy/periwinkle particulate composites was carried out using scanning electron microscope (SEM). The mechanical, physical and wear properties were carried out by standard methods equipment. The highest density was observed for the epoxy matrix at 1.76g/cm^3 and the least for 9wt% composites at 1.52g/cm^3, the highest water absorption was observed in the matrix at 1.5% and the least with 9wt% composites at 1.18%.The 9wt% composites had the highest hardness value at 76.4HV while the epoxy matrix had the least hardness at 39.8HV, the highest tensile result was observed in the 9wt% composite with a value 304 N/mm^2 while the least value was observed with a value of 287 N/mm^2 for the epoxy matrix. The microstructure of the composite is uniformly distributed and strong interfacial bonding occurred between the epoxy matrix and reinforcement; however agglomeration of particles were observed. The highest wear rate was observed in the epoxy matrix at 0.445mm^3/m while the least wear rate was observed in 9wt% epoxy composite at 0.272 mm^3/m.The development of the composite will contribute to knowledge helping to convert waste to wealth and reduce environmental pollution. The produced composites can be used in the production of plastic pipes for oil and gas industries.

Keywords: Epoxy, Periwinkle, Mechanical and Wear

I. Introduction

Advanced composite materials exhibit desirable physical and chemical properties that include light weight coupled with high stiffness, and strength along the direction of the reinforcing particulates, dimensional stability, temperature and chemical resistance, flex performance, and relative ease of processing. However, much of the advanced composites manufacture technology is progressively evolving. Among epoxies, phenolics, polyurethanes and polyimides which are matrix materials commonly used in the development of advanced composite materials, epoxy resins currently dominate due to their superior thermal, mechanical and electrical properties, dimensional stability and chemical resistance (Njjuguma *et al.,* 2007).

In its most basic form a composite material is one which is composed of at least two elements working together to produce material properties that are different from the properties of those elements on their own. In practice, most composites consist of a bulk material (the ‘matrix’), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix (Onuegbu & Madufor, 2012).

Polymer composite materials are multi-component materials comprising at least one type of continuous phase (polymer matrix) and fillers (fibers, plates, particles, etc.). Polymeric composites are widely used for structural, aerospace, and automobile sectors due to their good combination of high specific strength and specific modulus. These two main characteristics make these materials attractive, compared to conventional materials like metal or alloy. Some of their typical benefits include easy processing, corrosion resistance, low friction, and damping of noise and vibrations (Şahin, 2015).Organic fillers produced from agricultural wastes have gained tremendous attention from plastic industry, with primary advantages of low densities, low cost, non-abrasiveness, high filling levels, low energy consumption, biodegradability, availability of a wide variety of fibres throughout the world and generation of a rural/agricultural-based economy (Onuegbu & Madufor, 2012).

However, epoxy resins possess other favorable properties such as strong adhesion to many materials, good mechanical and electrical properties, relatively high chemical and moderate thermal resistance. Also epoxy in moulded or cast form has excellent dimensional stability and low shrinkage.

Particulate periwinkle shell was reported to improve the tensile strength, compressive strength, wear resistance and also lowers the density of composites. Higher mechanical properties were achieved with smaller particle sizes. The shell is an external

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exoskeleton which protects the periwinkles from their predators and mechanical damage. These snails called periwinkle are found in the lagoons and mudflats of the Niger Delta between Calabar in the East and Badagry in the West of Nigeria, the people in this area consume the edible part as sea food and dispose the shell as a waste (Onyechi*et al.*, 2015).

Much research efforts are geared towards possible ways of recycling wastes for reuse to keep environment clean and safe (Atuanya*et al.,* 2014). Hence, the use of periwinkle shell particulate (uncarbonized) in producing epoxy composites is therefore hoped to convert wastes to wealth, tackle the problem of environmental pollution, reduce the material cost and produce composites that can be used in production of pipes for oil and gas and aerospace applications.

II. Experimental Procedure

The epoxy resin, curing agent and the accelerator were methyl-5-norbornene-2,3-dicarboxylic anhydride(HY906) and benzyl dimethyl amine (DY062) which were purchased from Steve-More chemical shop in Zaria, Nigeria while periwinkle shells were procured from a market in Lagos, Nigeria. Other materials used are lubricant, oven, electronic weighing device and measuring cylinder. The periwinkle shells were washed and dried for four days and then crushed and pulverized using Jaw Crusher Machine to a particle size of $<10\mu m$.

Methods

Production of the composite

The composites were developed using hand lay-up procedure (Rabiu and Muhammed, 2020). Charge preparation was used to calculate the amount of constituents needed for the production of the composites. The control (unreinforced) samples were first produced using wooden mould followed by 3wt%, 6wt% and 9wt% periwinkle shell particles respectively. The composites developed were machined to the desired test samples.

Density measurement

The densities of the composites were determined using Archimedes principle. The weighed samples were recorded and the volume of the composite samples produced was measured by dipping in a measuring cylinder containing water. The displaced volume was recorded the densities were calculated using

$$\text{Density} = \frac{Mass}{Volume} \ (\text{kg/cm}^3)$$

Water absorption

The water absorption measurement was carried out by submerging the weighed samples in a calibrated beaker containing water for 30 days. The submerged samples were removed, dried and re-weighed. The percentage increase in weight is reported as the water absorption of the composite material

$$\text{Water absorption} = \frac{m2-m1}{m1} \times 100\%$$

m_2 = final mass of sample

m_1= initial mass of sample

Hardness test

The samples prepared for hardness test were polished and subjected to Vickers Hardness test using Finlab Vickers Hardness Tester, Model MVI-PC, 07/2012-1329. Three indentation points were recorded and the average was computed.

Tensile test

The samples were subjected to tensile test in accordance with ASTM 8m-91 standard specifications. The composite samples were machined and tensile test was performed at room temperature (25^0C) using Instron Universal Testing Machine 3369- Load Cell Capacity 50 KN operated at a strain rate of 10^{-3}/s. The evaluated tensile property from the stress strain curve is ultimate tensile strength.

Tribological test

The machine used is the CMS tribometer. Dry sliding wear test was carried out using four constant parameters which include, applied load (5N), sliding speed (10cm/s) and sliding distance (40m). The responses studied are wear and frictional coefficient.

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Scanning electron microscope (SEM)

The polished sample of the 9wt% epoxy composite was taken for SEM analysis. The sample was exposed to ZEISS EVO/LS10 microscope and images were taken at different magnifications.

III. Results and Discussion

Density

The results of the density test are shown in Figure 1. It can be observed that the densities of the composites are lower than the matrix. The highest density was observed for the epoxy matrix at 1.76g/cm^3 and the least for 9wt% at 1.52g/cm^3. The decrease in density values may be attributed to the presence of reinforcement in the composites as reported as by (Ngargueudeaji m*etal.*, 2015)

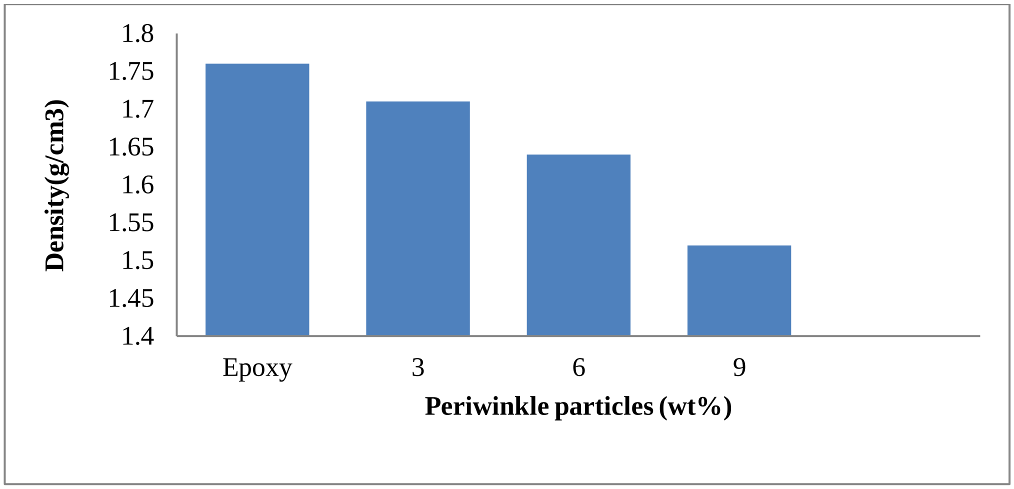

Figure 1: Variations of density with periwinkle particles

Water absorption

The results of the water absorption test are shown in Figure 2. The water absorption of the composites decreased as the reinforcement content increases. The highest water absorption was observed in the matrix at 1.5% and the least with 9wt% at 1.18%. The higher water absorption value of the matrix compared to the composite may be attributed to the hydrophobic nature of the reinforcement (Sreekala *et al.*, 2002).

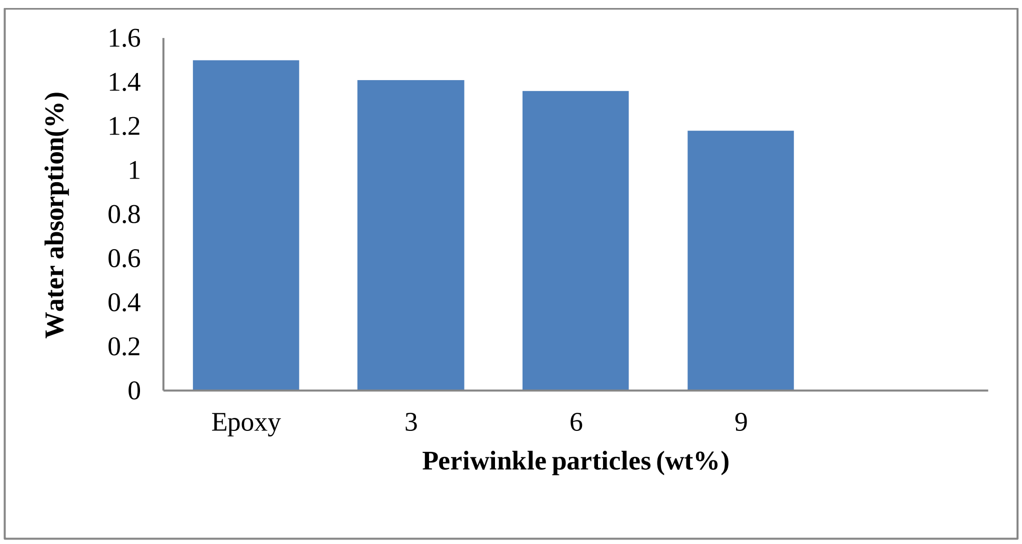

Figure 2: Variations of water absorption with periwinkle particles

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Hardness results

The results of the Vickers hardness test are presented in Figure 3. It can be observed that the periwinkle particulates contributed positively to the hardness of the composites. The 9wt% composite had the highest hardness value at 76.4HV while the epoxy matrix had the least hardness at 39.8HV. The increase in hardness can be linked to the presence of reinforcement in the matrix as reported by (Mulinari *et al.*, 2011)

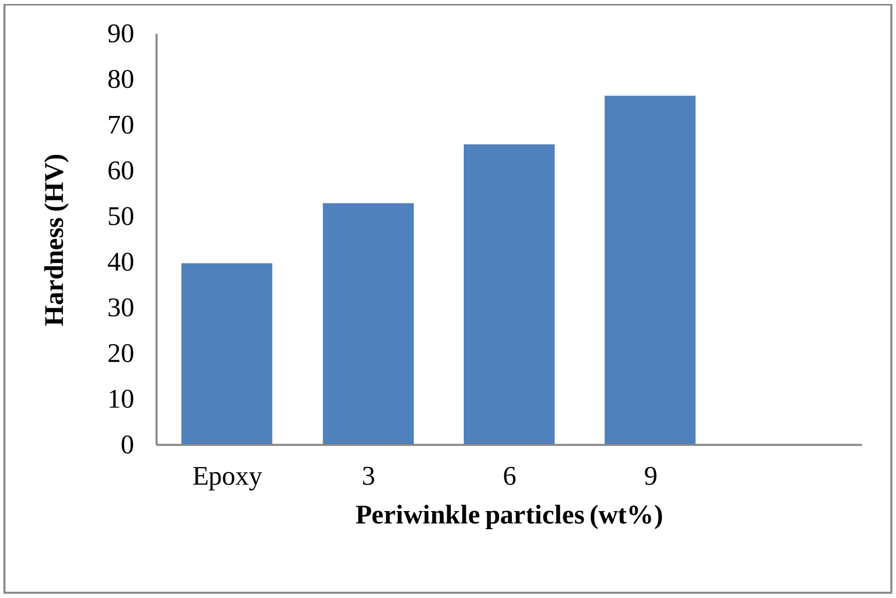

Figure 3: Variations of hardness with periwinkle particles

Tensile results

The tensile results are shown in Figure 4.It can be observed that the highest tensile result was observed in the 9wt% composite with a value 304N/mm^2 while the least value was observed with a value of 287N/mm^2 for the epoxy matrix. The increased tensile strength can be attributed to matrix strengthening and strain hardening behaviour of the periwinkle particles as reported by (Auradi*et al.*, 2014)

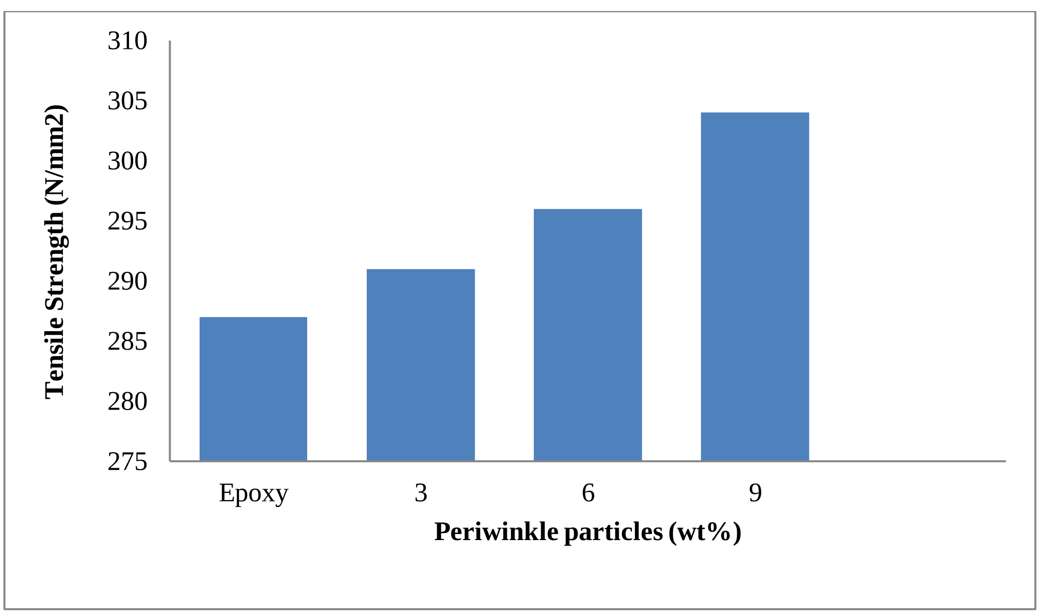

Figure 4: Variations of tensile strength with periwinkle particles

Scanning Electron Microscopy

The SEM micrograph shows good interfacial adhesion between the particulates and matrix and fewer voids were observed due to the presence of periwinkle filler.

The epoxy phase looks faded probably due to over etching, however agglomeration was observed as result of segregation of the particulates in the matrix. The SEM images generally show a clearer and detail structure. These features have also been reported by (Babic*et al*2009).

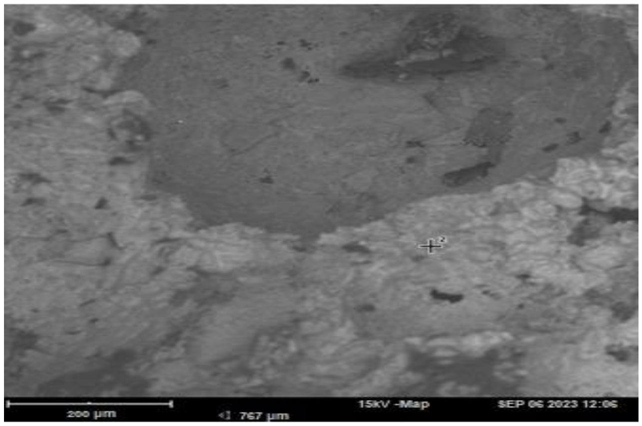

Plate I: Surface SEM of 9wt% epoxy composite

Tribological results

The Figures 5 shows the variations in the tribological test for the matrix and the epoxy/periwinkle composite.

The mean wear rate is lower for composites compared with the epoxy matrix. It can be seen that the jerking friction occurred on the interfaces between the epoxy and the periwinkle particles at 40m sliding distances; there was no jerking friction at the initial stage of the test because the smooth surface were later abraded as the test continued. The highest wear rate was observed in the epoxy matrix at 0.445mm^3/m while the least wear rate was observed in 9wt% epoxy composite at 0.272 mm^3/m

The nearly stable friction can be attributed to non- presence of asperities to resist the movement of the epoxy phase.It was observed that the coefficient of friction decreased as temperature and applied load for composite increases.

A low wear rate and low and steady frictional coefficient are the main properties required of wear-resistant materials (Zhu and Hong, 2017).

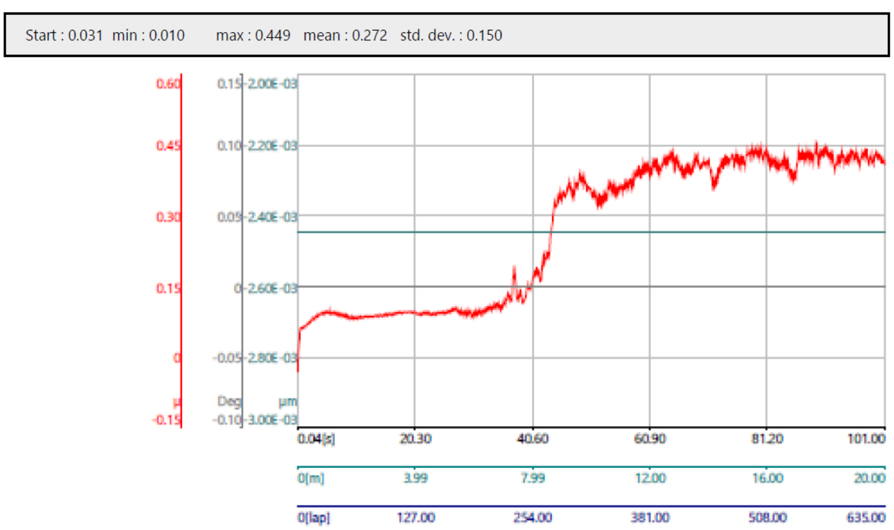

Figure 5a: Variations of tribological result of 9wt % epoxy composite

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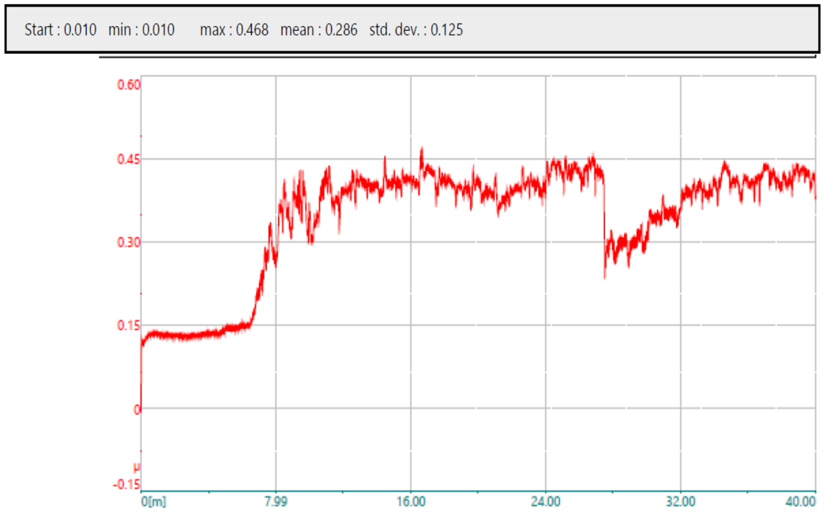

Figure 5b: Variations of tribological result of 6wt % epoxy composite

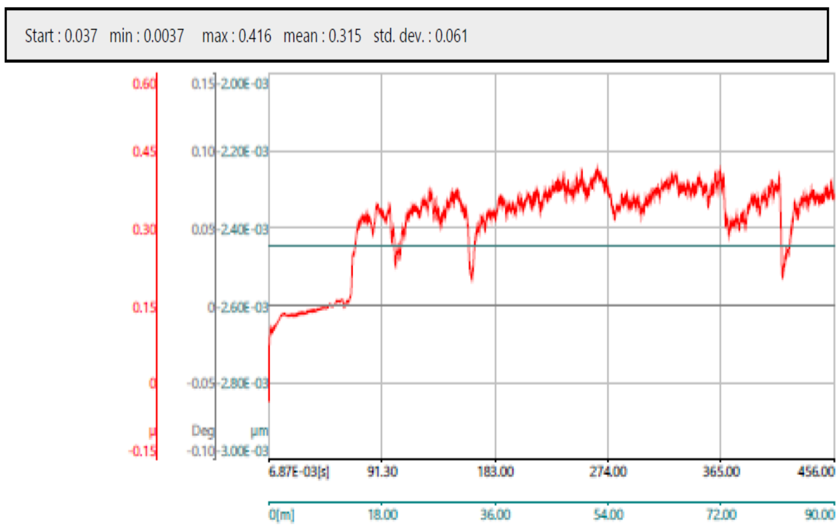

Figure 5c: Variations of tribological result of 6wt % epoxy composite

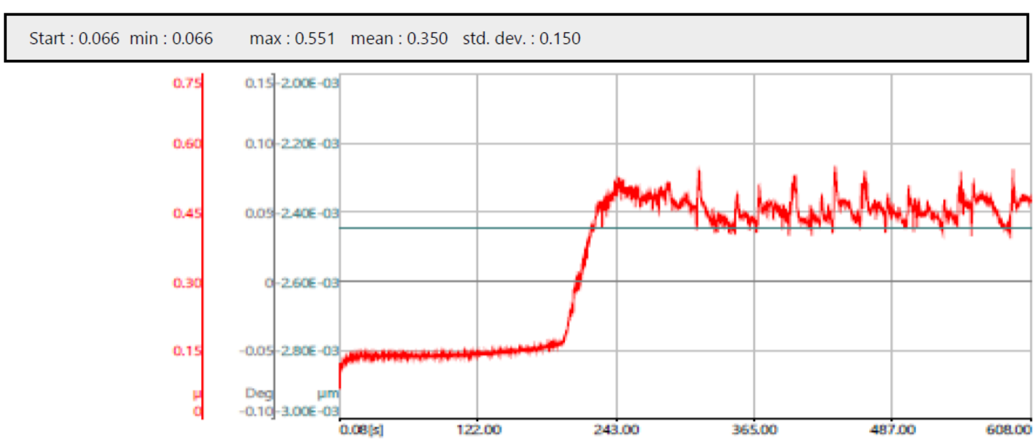

Figure 5d: Variations of tribological result of epoxy matrix

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IV.Conclusions

Conclusions

The following conclusions have been drawn:

I. The composites were developed by incorporation of periwinkle shell particles in the epoxy matrix by hand lay-up method

II. The microstructure of the composite is uniformly distributed and strong interfacial bonding between the epoxy matrix and reinforcement was observed; however agglomeration of particles were observed.

III. The density of the composites are lower than that of the unreinforced epoxy matrix

IV. The composites possess better tensile and hardness as compared with the unreinforced epoxy.

V. The water absorption results showed a lower water intake for the composites compared with the epoxy matrix.

VI. The wear results showed a lower wear rate and friction compared with the epoxy matrix.

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