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# Dynamic Mechanical and Morphological Characterization of Treated *Prosopis africana* Wood fiber Reinforced Polyvinyl Chloride Composites

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## ABSTRACT

In this work, the effect of *Prosopis africana* (PA) on the viscoelastic properties of PVC composites was examined using the dynamic mechanical analysis technique and scanning electron microscopy to ascertain the interaction of the PVC and the PA fibre. In order to improve adhesion between the hydrophilic natural fiber and the hydrophobic plastic matrix, the PA fiber was treated with a sodium hydroxide solution. The amount of fiber loading ranged from 0, 4, 8, 12, 16, 20 to 24, but the bulk of this work considered 12% wt composition because it correlates to higher mechanical properties. This work was carried out to further investigate the dynamic mechanical and morphological properties of the composite sample with the optimum properties (12% wt composition). When compared to unreinforced polyvinyl chloride, the dynamic mechanical characteristics such as storage modulus and damping all significantly improved: Storage modulus (4.0 GPa) compared to (1.8 GPa) of unreinforced PVC while the loss modulus decreased; indicating an improvement of PVC. Scanning electron micrograph of treated PA reinforced PVC composites showed fairly uniformly filled PVC (at 12 % wt) with less voids and fiber agglomeration. This indicates that the dynamic mechanical and morphological properties of PVC could be enhanced by the incorporation of treated PA fibres.

**Keywords**: Analysis, Composites, Dynamic, PVC, *Prosopis africana*

## INTRODUCTION

Poly (vinyl chloride) often known as PVC, is a type of thermoplastic polymer that is currently influencing many facets of life due to its widespread use and status as an all-purpose material (Sheng *et al.,* 2012). Reinforcing fillers are combined with the polymer matrix to create polymer composite, a multi-phase material that possesses synergistic mechanical qualities that cannot be obtained from either component alone (Chawla, 2013). A innovative, environmentally friendly composite material called wood plastic composites is made of thermoplastic resin reinforced by wood particles or fibers. (Chen *et al.*, 2018). Due to their numerous outside applications, polyethylene, polypropylene, and PVC are the most common thermoplastic polymers utilized in wood plastic composites. Construction, marine automobile, and aerospace industries are dominated by composite materials composed of reinforced polymers with aramid, carbon, and glass fibers. (Abdrahman and Zainudin, 2011).

However, due to their demonstrated superior performance to synthetic fibers in a variety of composite applications, scientists and engineers have recently shown a greater interest in researching natural fiber-based composites. In addition, the need to reduce the overdependence of fossil based fuels, there is increased interest of researchers to maximize the use of renewable materials like the natural fibres in composite manufacture (Jacob and Mamza, 2021; Yusuf *et al.*, 2020).

According to Cole (2017), the global market for wood plastic composites is anticipated to increase at a rate of around 13.2% over the following ten years, reaching roughly $9.7 billion by 2025. Additionally, in addition to the formal regulations, researchers and automakers are compelled to lower greenhouse gas emissions. This is accomplished by employing application-oriented material and better motor technologies to lighten the structure's weight (Stadler *et al.*, 2020). In order to satisfy the demands of end user applications, solid research is required to provide superior performance characteristics for these constantly growing wood plastic composites (WPC). In order to enhance the physical, mechanical, and thermal properties of PVC, a number of works have been reported on its reinforcement (Khan *et al.*, 2011; Ali *et al.*, 2021 and Jacob *et al.*, 2022). However, much has not been reported on the dynamic mechanical and morphological properties of *prosopis africana* filled PVC composites. It has become pertinent to investigate how the incorporation of PA fibres into PVC could influence its thermal and morphological properties.

## MATERIALS AND METHODS

### Sampling procedure

The *Prosopis africana* log was obtained from Hannu-Tara in Dansadau, Maru Local Government, Zamfara State, Nigeria. Locally, the log is known as *Kiriya* in Hausa and *Ayan* in Yoruba. The wood was divided into pieces and then dried in the sun for seven days in order remove any moisture before being ground into a powder. Then it was sieved using a 150 µm mesh.

### Chemical treatment of the *Prosopis africana* fibres

This was aimed at chemically modifying the fibers and to minimize moisture absorption and by an increase in bond strength with the hydrophobic PVC matrix. 10% NaOH (from BDH supplies, England, UK) solution was added to sufficient amount of PA fibres for 5 hours with constant stirring. It was then rinsed with distilled water until the solution was neutral. It was then decanted off and vacuum dried at 80°C for 5 hours for further use (Jacob *et al.*, 2018a).

### Preparation of the PVC-*prosopis africana* wood composites

The PVC resin was obtained from Iddo Plastic Ltd, Lagos (grade: SG5, appearance: white powder, particle size: 2.0max) was obtained from and *Prosopis africana* were prepared by compounding and compression molding techniques two roll mill (Model No. 5183, New Jersey, USA). Composite samples were prepared by adding PVC resin while running the roller counterclockwise for 10 min at a temperature of 250 °C. Once the pasty matrix was formed, the filler (*Prosopis africana powder*) was carefully manually introduced while rotating the roller at a speed of 500 rpm. The fiber load varied as follows: 0, 4, 8, 12, 16, 20 and 24% while the amount of PVC was maintained at 96, 92, 88, 84, 80 and 76%, respectively.

### Dynamic Mechanical Analysis (DMA)

Dynamic mechanical analysis was carried out using DMA 242E machine in strength of materials Laboratory, Mechanical Engineering Department, ABU Zaria according to (ASTM D7028, 2015). The storage modulus, loss modulus, damping (tan delta) and glass transition temperature of the composites were all evaluated from the proteus software of the DMA machine.

## RESULT AND DISCUSSION

### Storage modulus

Polymeric materials' storage modulus (E') demonstrates how stiffer they are (Gupta, 2018). Additionally, it illustrates the elastic component and describes the energy that is held inside the system (Jacob *et al.*, 2019). The storage modulus curve of pure PVC is shown in Figure 1 for frequencies of 2.5, 5, and 10 Hz, respectively. With a maximum stiffness stability of 1.70 GPa at 10 Hz and a glass transition temperature of 53 °C, the curve demonstrates that unreinforced PVC is unstable at temperatures over 60 °C up to 100 °C.

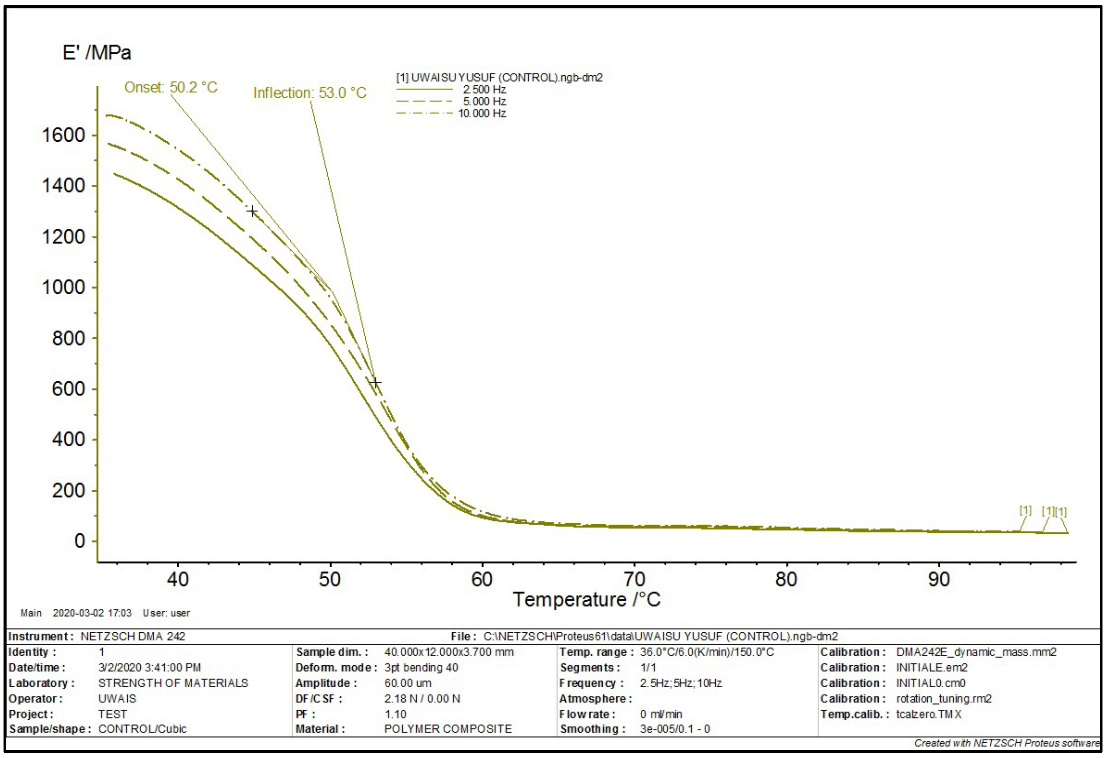


**Figure 1: Storage modulus curve of pure PVC at 2.5, 5, and 10 Hz**

Figure 2 shows the storage modulus curves of the 12 wt% PA-PVC composite at three different frequencies (2.5, 5 and 10 Hz). The storage modulus of PA-PVC is found to increase with increasing frequency but decrease with increasing temperature, with a maximum value of 4.0 GPa at 10 Hz and a minimum value of 3.7 GPa at 2.5 Hz. This may be due to short-term applied stress, as the stress is effectively transmitted by the increased frequency. However, the lowest value at frequency 2.5 Hz may be due to poor transfer of stress from the matrix (PVC) to the fibre (PA). From this figure, it can be seen that the maximum stiffness stability of the PA-PVC composite is 4.0 GPa at a glass transition temperature of 55.6 °C. This indicates that incorporating PA wood fibers into PVC increased its stiffness by 2.3 GPa and its glass transition temperature by 2.6 °C. Therefore, reinforcing his PVC with *Prosopis africana* wood fibers improved the thermal stability of the material. Similar results have been reported by other authors (Jacob *et al.*, 2019; Yusuf *et al.*, 2020).

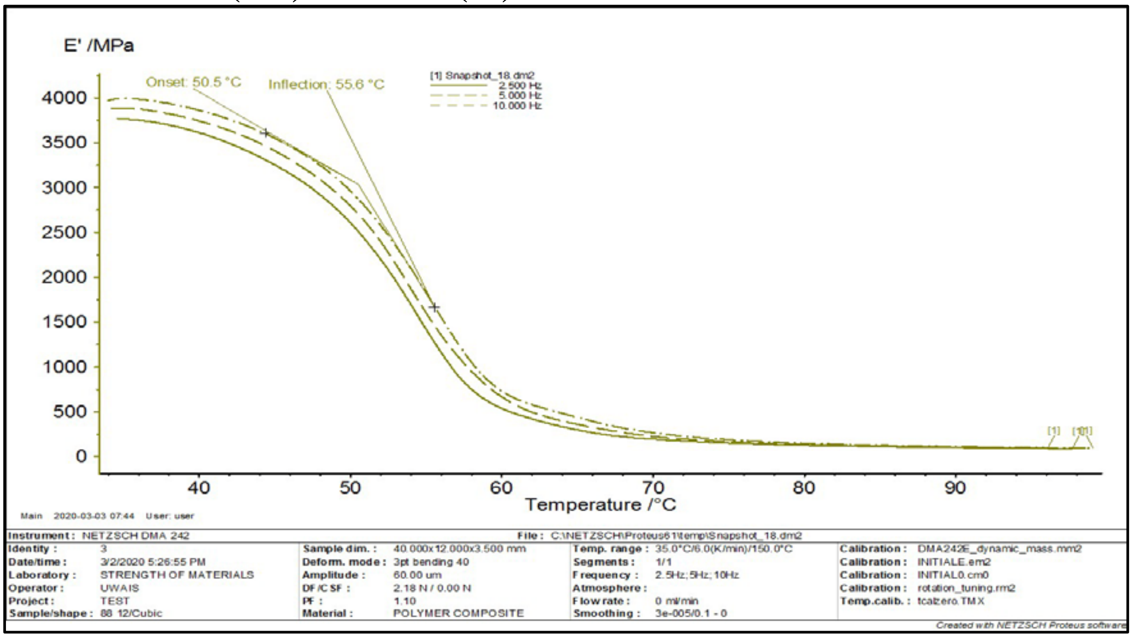


**Figure 2: Storage modulus curve of 12 % PA-PVC composite at 2.5, 5, and 10 Hz**

**Loss modulus**

The highest amount of energy released by a polymeric material during deformation is known as the loss modulus (Gupta, 2018). The loss modulus of 12% weight PA-PVC composites is shown in Figure 3. The values of loss modulus were seen to grow up till the glass transition temperature. At 53.6 °C, the loss modulus of the 12% PA-PVC composite reached its greatest peak. This is regarded as the material's glass transition temperature.

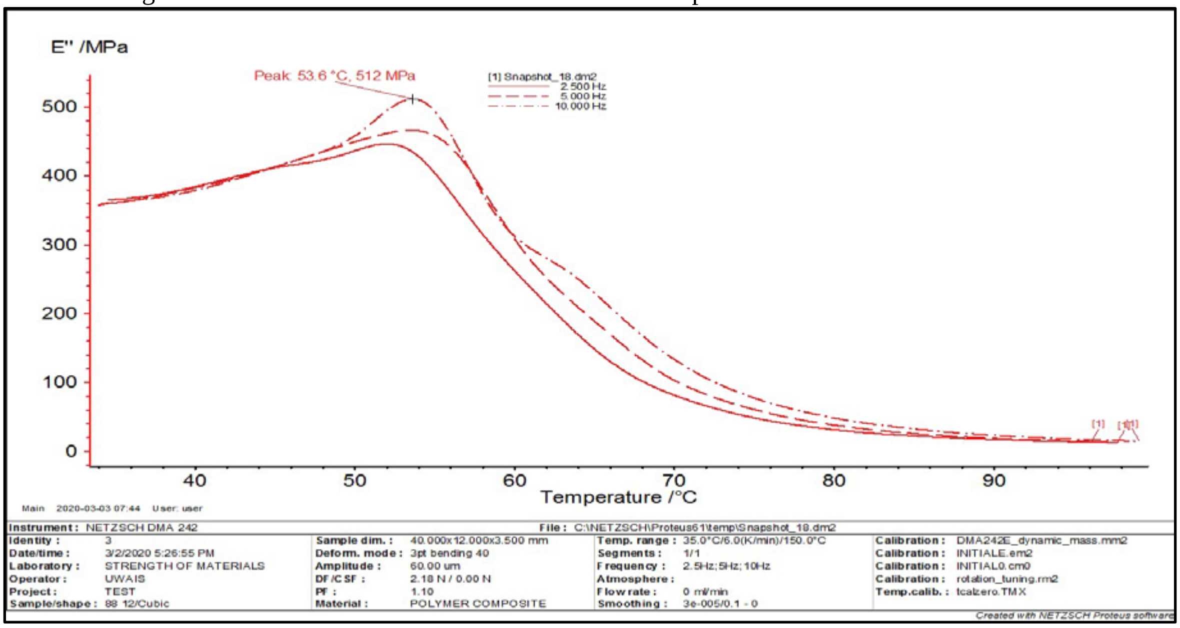


**Figure 3: Loss modulus curve of 12 % PA-PVC composites at 2.5, 5 and 10 Hz.**

**Damping**

The damping factor is the ratio of loss modulus to storage modulus. In a polymeric structure, the damping characteristics of a material determine how the elastic and viscous phases are balanced (Palavinel *et al.*, 2017). The adherence of the fibers to the matrix affects damping. Higher damping and lower fibre-matrix adhesion are related, and vice versa (Gupta, 2018). The damping curve of 12% weight PA-PVC composites at 2.5, 5 and 10 Hz frequencies is shown in Figure 4. In comparison to all other frequencies, 10 Hz showed the largest peak of damping and better damping values. It could be observed from the results that there was an improvement in dynamic mechanical properties of the PA filled PVC composites with increase in frequencies. Similar result of increase in dynamic mechanical properties at higher frequencies has been reported (Jacob, 2023). This may be attributed to the effective stress transfer between the PA wood fiber and PVC matrix as a result of high fibre-matrix adhesion. Similar trend in the Tan delta result was observed by other authors (Tian *et al.,* 2021; Bashir, 2021; Jacob and Mamza, 2021).

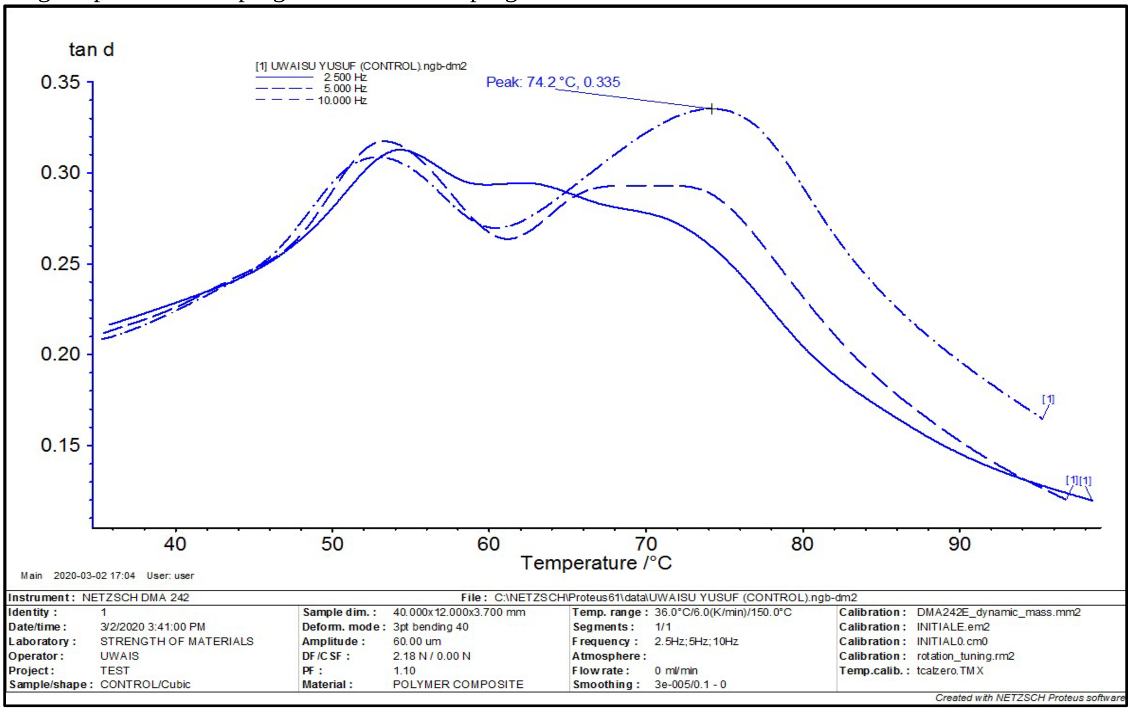


**Figure 4: Damping curve of PVC at 2.5, 5 and 10 Hz**

**Morphological properties**

Plate 1 shows the SEM micrograph of unreinforced PVC at X1000 magnification. Presence of voids could be observed, this may be attributed to improper mixing of the PVC matrix during compounding and compression processes.

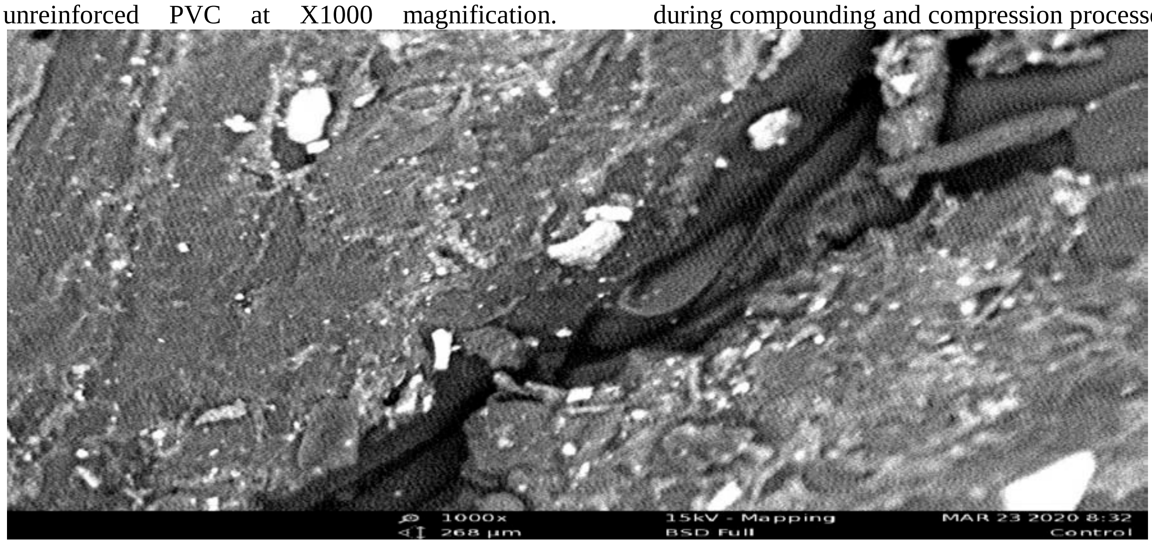


Plate I: SEM micrograph of pure PVC at X1000 magnification

Plate II and III depict the morphologies of 8 %wt PA reinforced PVC and 12 %wt PA reinforced PVC composites at X1000 magnifications. It could be observed that there are little voids and fiber agglomeration in 8 % wt PA reinforced PVC sample (Plate II) which was observed to considerably reduce at 12 % wt PA reinforced PVC (Plate III). This indicates a lower interfacial adhesion with the polymer matrix, explaining the inferior mechanical properties observed at lower reinforcement weight fractions. However, at higher weight fractions of reinforcement (Plate III), smaller voids and reduced fiber cohesion were observed, indicating better interfacial adhesion between the PA wood fibers and the PVC matrix.

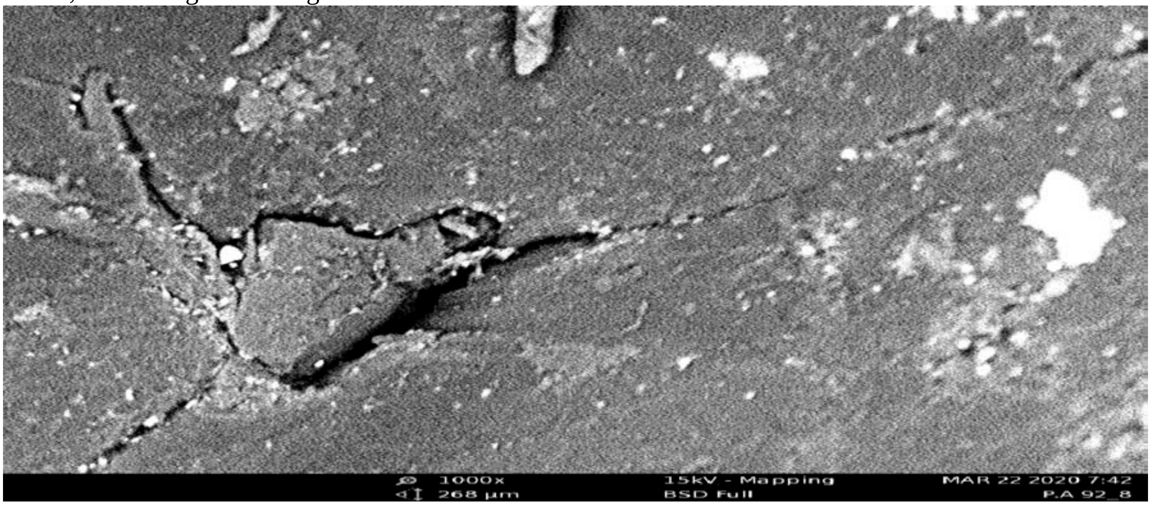


**Plate II: SEM micrograph of 8 % wt PA reinforced PVC composite at X1000 magnification**


**Plate III: SEM micrograph of 12 % wt PA reinforced PVC at X1000 amgnification**

**CONCLUSION**

Dynamic mechanical properties results indicated that reinforcement of PVC using treated PA wood fibres improved its visco-elastic properties. The effect of variation in frequencies investigated at 2.5, 5.0 and 10.0 Hz showed an increase in dynamic mechanical properties at higher frequency (10 Hz). The storage modulus was observed to increase while the energy dissipation of the composite materials decreased with a maximum value of 4.0 GPa for 12 % PA-PVC composites compared to 1.7 GPa of the unreinforced PVC at 70 °C. Scanning electron micrograph of treated PA reinforced PVC composites showed fairly uniformly filled PVC (at 12% wt) with less voids and fiber agglomeration. This explained the observed improved dynamic mechanical properties of the PA filled composites.

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