The Effect of Alkali Treatment to Mechanical Properties of Resin Composite Reinforced with Coir Coconut Fiber

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ABSTRACT

Previous research related to the effect of alkali treatment on mechanical properties of composite materials which generate the regression model is still rare. From the previous research, alkali treatment does not always improve the mechanical properties of composite materials. Therefore, it is necessary to research to make sure the effect of alkali treatment on coconut fiber composite. This study aims to examine the effect of alkali treatment of fiber combined with fiber weight content on the mechanical and physical properties of epoxy resin matrix composite. Mechanical properties testing is done by impact test and torsion test. The fracture surface was observed using optical microscopy. Data from the test results were analyzed to see the effect of alkali treatment on the mechanical properties of the resulting composite material by generating the regression model of impact strength and shear strength for treated and untreated fiber composites. The coefficient of determination (R^2) of all models was 1. This study obtained that the untreated fibers have better impact strength and shear strength than the treated ones. The highest impact strength, 7.07 kJ.m^2, and the highest shear strength, 1.81 MPa were obtained from the samples containing 4% untreated fibers.

Keywords: *Alkali Treatment; Untreated; Mechanical Properties; Resin; Coconut Fiber*

Introduction

Composite materials have recently been used as a substitute for metal materials. Along with these developments, an increase in the mechanical

ISSN 1823-5514, eISSN 2550-164X

Received for review: 2021-10-21
Accepted for publication: 2022-02-28
Published: 2022-04-15

properties of composite materials is very much needed, considering that their use extends to structural materials that retain loads [1]. For example, metal material that undergoes the welding process should be tested the dynamic toughness by the Charpy impact test [2]. Therefore, the composite material which will be used for structural material also needs to be impact tested or other mechanical properties [3].

The mechanical properties of composite materials have been widely studied by researchers around the world, both composites with synthetic reinforcement [4] and natural fiber reinforcement [5, 6]. A study on the structure and performance of composite polylactic reinforced with oil palm empty fruit bunches with alkaline and ultrasonic treatments [7]. Arumunga et. al. [8] conducted a study on the mechanical, damping, and chemical resistance properties of banana fiber hybrid composites, Widyaningsih and Sutanto [9] studied the influence of hyacinth plant as filler on mixed Ac-WC (asphalt concrete-wearing course) with marshall test. While Godze et al. [10] conducted a study on the mechanical performance and resistance of castings reinforced with treated fibers. Other researchers [11]–[13] conducted a study on the mechanical properties of natural fiber-reinforced composites for engineering applications. Even lately, studies on mechanical properties of composite material are also related to manufacturing processes like additive manufacturing (3D Printing), etc. [14].

Many factors are affecting the mechanical properties of composite materials that have been studied by researchers in the world. Previous research has proven that the mechanical properties of composite materials are influenced by the content of the fiber, the hardener, and the epoxy resin fraction [15] and also the direction of the woven fiber [14].

Research on the effect of oil palm fiber content on the axial load fatigue cycle on resin matrix composite has been conducted. That study obtained that The impact strength of the composite material is influenced by the fiber length and fiber content [16][12]. Other researchers, who examined the effect of weight percentage on the tensile strength and flexure of coconut coir polyester fiber composites found that the percentage of 15% fiber weight has the highest average tensile strength of 24.478 MPa compared to 5% and 10% fiber fractions [17].

The impact strength study of composite materials has also been carried out [17][16]. That research a polypropylene matrix and oil palm fiber reinforcement. From this study, it was found that the highest impact strength was obtained in specimens with 10% weight fiber content compared to 5% and 7%. Regarding fiber length, it was found that the highest impact strength was obtained in specimens with a fiber length of 10 mm compared to the fiber length of 5 mm and 7 mm [16, 17].

Regarding mechanical properties testing, the type of load on a structural material can be static, dynamic (fluctuating), or shock loads. The results of these tests are to ensure the ability of the material to withstand these loads. The ability of the material to static load is usually done by testing the tensile strength of the material. To determine the ability of the material to withstand dynamic loads is done by fatigue tests, while to determine the ability of materials to impact loads is done by impact testing.

There were many studies have been carried out by researchers to improve the mechanical properties of composite materials. Among them, a study of using the alkali treatment of oil palm empty fruit bunches [16]–[18], and also henequen fibers [19] have been conducted. From those studies, different results have been obtained. Alkali treatment of certain fibers can improve their mechanical properties significantly, but on the other fibers, the effect is not significant, or even reduce the mechanical properties of the composite material. It can be concluded that the effect of the alkali treatment on the fiber during manufacturing the composite materials on each type of fiber is different.

The above studies have not examined the effect of alkali treatment on the mechanical properties of coir coconut fiber reinforced resin composites. Therefore, in this research, an alkali treatment of coir coconut fiber will be carried out and then the mechanical properties produced between the alkali-treated fibers and the untreated ones are examined.

The availability of coir coconut fiber is abundant in Indonesia and is a significant contributor to the volume of organic waste. Therefore, the use of coconut fiber waste for the manufacture of composite materials is urgent to be applied. However, considering that the mechanical properties obtained in the polymer composite material reinforced with coconut fiber are still not so good, it needs to be improved in various ways. One of them is alkali treatment on fiber. However, based on the above background, it has been seen that the alkali treatment of various types of fiber gave different results. To ensure this, it is necessary to conduct research for determining the effect of alkali treatment on coir coconut fiber which will be used as a reinforcement of composite materials.

The objectives of this study were to obtain mechanical properties of resin composite materials reinforced with treated and untreated coir coconut fiber. Other than that, also investigate the effect of alkali treatment on the mechanical properties of coconut fiber reinforced resin composite materials.

The mechanical properties of coconut coir fiber reinforced epoxy composites have been investigated especially for tensile strength [20]. That study concluded that the optimum fiber content of coir coconut fiber resin composite is 5%. This research has not investigated the impact strength and shear strength of the coconut fiber-reinforced resin composite material. Therefore, this research was focused on research related to impact strength and shear strength for Epoxy EPR174 resin and V-140 hardener with the selected fiber weight fraction of 2%, 4%, and 6% while the hardener fraction is 0.5.

Methodology

The flow of the research is shown in Figure 1.

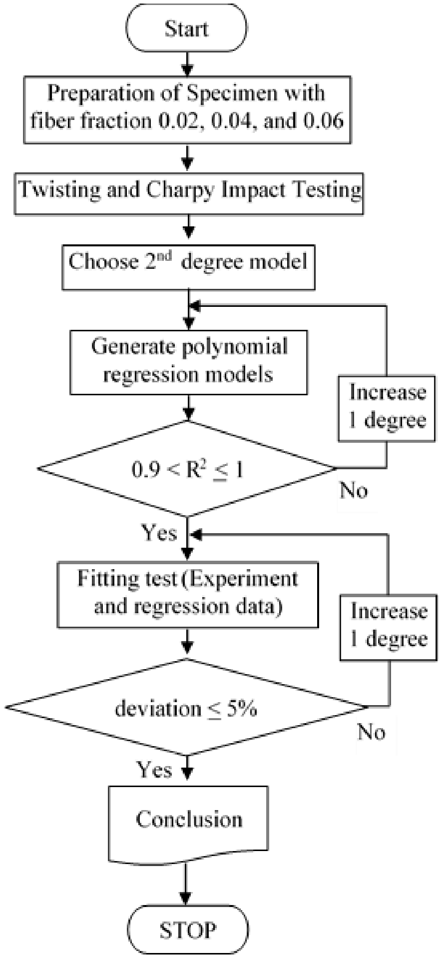

Figure 1: Research flow chart

The study began with the preparation of tools and materials for manufacturing the specimen samples. Then proceeded with impact testing, twist testing, and observation using OM (Optical Microscopy). The impact test results were used to calculate the impact strength of the specimens for the analysis. Twisted testing was conducted to obtain the shear stress and shear strain of the specimen. Then the regression models were made of impact strength and shear stress for alkali-treated and untreated fiber composites using Microsoft® Excel® 2019 MSO. The variable in the regression model is fiber fraction.

The validation processes involved in the regression equation were checked by the value of the determination coefficient (R^2), which in ordinary least squares, the range between 0 and 1. The best validity should have $R^2 = 1$. However, it cannot be guaranteed that an R^2 close to 1, the model fits the data well. Because the high R^2 can occur in the presence of other factors like the presence of outliers that distort the true relationship etc. Therefore, to ensure the validity of the regression model again, it is done by fitting the models to the experimental data. The models are declared valid when the deviation is below 5%.

Material preparation

The coir coconut fibers were washed with lots of water and dried until completely dry. Then the clean coir coconut fibers are cut short by less than 4mm and separated into two groups, treated fiber, and untreated fiber.

Manufacturing of the specimen is done to follow the specimen size according to ISO 179-1: 2000 standard [21, 22] for Charpy impact test specimen and ASTM E-143 [23] for Twist test specimen. There were 2 factors. The first factor studied was alkali treatment which consists of 2 levels: alkali-treated and untreated. The second factor was fiber content which consists of 3 levels i.e.: 2%, 4%, and 6%.

The study was designed to follow the full factorial design, in which the numbers of samples combination types that must be prepared were: 2 x 3 = 6 type combinations. Each type was made with 5 samples. So that the total numbers of samples were 30 samples for each test (Charpy impact and Twist test which consist of 15 treated fiber samples and 15 untreated fiber samples.

The specimen of impact testing was tested using a plastic material Charpy impact equipment of the brand Wolpert with a maximum capacity of 4 J, and the twisting test was used a metal and composite material twisting test machine with a maximum shear stress capacity of 1000 MPa which located at Mercu Buana University's mechanical engineering laboratory. Likewise, OM observation was carried out using OM in the Mechanical Engineering Laboratory of Mercu Buana University.

Experimental Results

Specimen preparation is carried out to obtain specimen sizes according to ISO 179-1: 2000 standards for impact tests and ASTM E-143 as shown in Figure 2.

(a) (b)

Figure 2: The test specimens: (a) Impact, (b) Twisting

The impact test and twist test were done by the impact test equipment (for plastic materials) and the twisting or torque test equipment in the Mechanical Engineering Laboratory of Mercu Buana University. Likewise, The fracture morphology of the impact specimen is observed using optical microscopy in the Mechanical Engineering Laboratory at Mercu Buana University. The recapitulation of the impact test results is shown in Table 1.

Table 1: Recapitulation of impact test results

No	Code	Alkali treated/ Untreated	Content (%)	Impact energy (J)	Impact strength (kJ/m^2)
1	SF2	Un-treated	2	0.28	6.84
2	SF4		4	0.27	7.07
3	SF6		6	0.26	6.71
4	SA2	Alkali treated	2	0.18	4.80
5	SA4		4	0.14	3.48
6	SA6		6	0.15	3.84
10	Pure resin	-		0.064	1.37

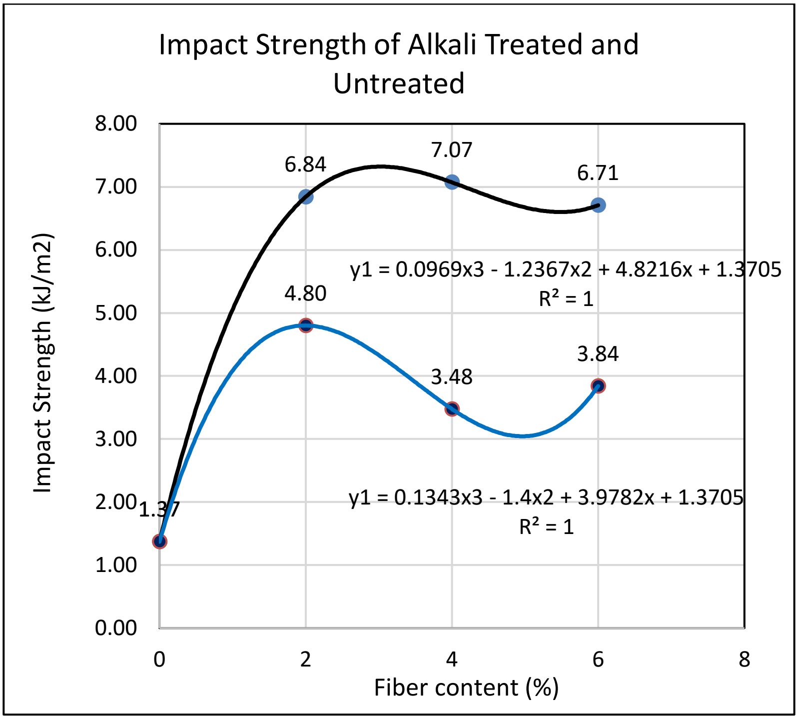

Figure 3: The impact strength regression models of alkali-treated (the blue curve) and untreated (the black curve) coir coconut fiber-reinforced composite

The impact strength regression models of alkali-treated and untreated coir coconut fiber-reinforced composite are shown in Figure 3. The regression equation of impact strength of untreated coir coconut fiber-reinforced composite is as follows:

$$y_1 = 0.0969x^3 - 1.2367x^2 + 4.8216x + 1.3705 \quad (1)$$

where y_1 is impact strength (kJ/m^2) and x is fiber content (%).

The coefficient of determination (R^2) of the regression equation is 1. It indicates that the percentage of fiber content of 100% affects the impact strength of the composite material. Or in other words, the variation in the percentage of fiber content in the composite material in this research is 100% able to explain variations in impact strength. The highest impact strength 7.07 kJ/m^2, is obtained by the samples with 4% fiber content.

The regression equation of the impact strength treated coir coconut fiber reinforced composite is as follow:

$$y_1 = 0.1343x^3 - 1.4x^2+3.9782x+1.3705 \tag{2}$$

where y_1 is impact strength (kJ/m^2) and x is fiber content (%).

The coefficient of determination (R^2) of the regression equation is 1. It indicates that the percentage of fiber content of 100% affects the impact strength of the composite material. Or in other words, the variation in the percentage of fiber content in the composite material in this research is 100% able to explain variations in impact strength. The highest impact strength 4.8 kJ/m^2, is obtained from the samples with 2% fiber content.

From the graph could be understood that alkali treatment to coir coconut fiber couldn't improve the impact strength of the composite material resulted.

Table 2: Recapitulation of torque test results

No	Code	Alkali treated/ Untreated	Content (%)	Shear Strength (MPa)	Shear strain
1	SF2	Untreated	2	0.95	0.82
2	SF4		4	1.81	0.34
3	SF6		6	0.60	0.13
4	SA2	Alkali Treated	2	0.53	0.44
5	SA4		4	0.33	0.26
6	SA6		6	1.69	0.49
10	Pure resin	-		0.05	0.02

The shear strength regression models of alkali-treated (the black line) and untreated (the blue line) of coir coconut fiber-reinforced composite are shown in Figure 4. The regression equation of the shear strength of alkali treated coir coconut fiber-reinforced composite is as follows:

$$y_2 = 0.0427x^3 - 0.2527x^2+0.1133x+0.05 \tag{3}$$

where y_2 is shear strength (kJ/m^2) and x is fiber content (%).

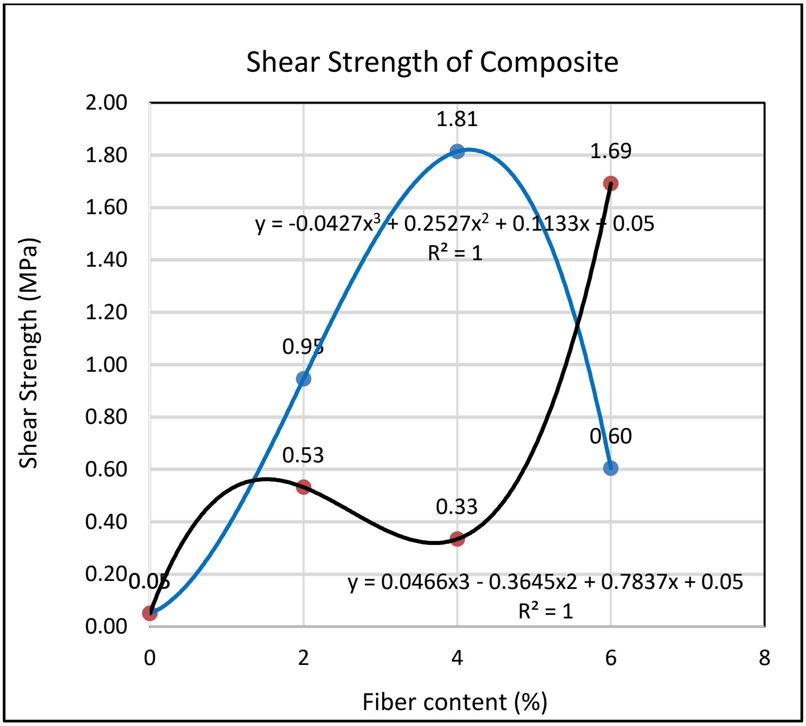

Figure 4: The shear strength of alkali-treated (black curve) and untreated (blue curve) fiber-reinforced composite

The coefficient of determination (R^2) of the regression equation is 1. It indicates that the percentage of fiber content of 100% affects the shear strength of the composite material. In other words, the variation in the percentage of fiber content in the composite material in this research is 100% able to explain variations in shear strength. The highest shear strength 1.81 MPa, is obtained from the samples with 4% fiber content.

The regression equation of the shear strength of untreated coir coconut fiber reinforced composite is as follow:

$$y_2 = 0.0466x^3 - 0.3645x^2 + 0.7837x + 0.05 \tag{4}$$

where: y_2 is impact strength (MPa) and x is fiber content (%).

The coefficient of determination (R^2) of the regression equation is 1. It indicates that the percentage of fiber content of 100% affects the shear strength of the composite material. Or in other words, the variation in the percentage of fiber content in the composite material in this research is 100% able to explain variations in shear strength. The highest impact strength 1.69 MPa, is obtained from the samples with 6% fiber content. From the graph could be understood that alkali treatment to coir coconut fiber couldn't improve the shear strength of the composite material resulted. The morphology of the specimen fracture from the impact test results was also observed using optical microscopy (OM). The results of this observation are shown in Figure 5.

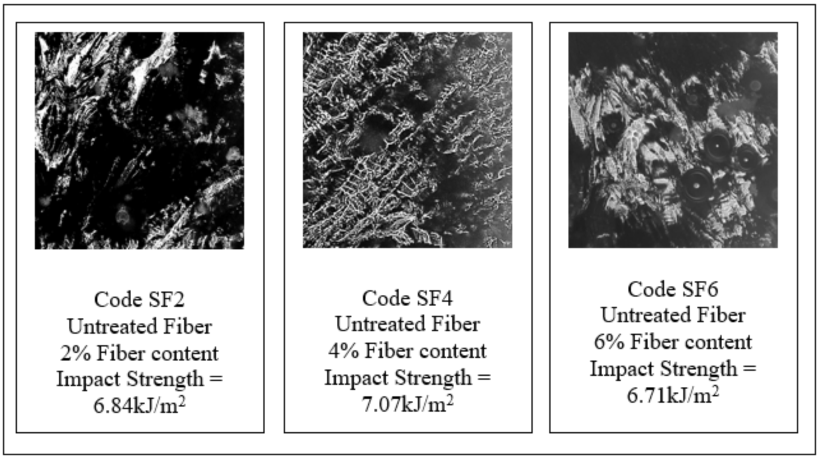

Figure 5: The fracture surface morphology of the impact test specimen of the composite resin reinforced with untreated coir coconut fiber. Observations were made using optical microscopy with a magnification of 100x

Figure 5 shows the fracture surface of 3 samples of specimens containing 2% (SF2), 4% (SF4, and 6% (SF6) samples. The highest impact strength was obtained in specimens with 4% fiber content, which was the impact strength of this specimen is also the highest compared to all specimens in this study. From the figure, it looks at the fracture surface of the SF4 specimen with a fiber content of 4%, the fibers are evenly distributed, so that the bond between the fibers and the matrix is also evenly, resulting from high impact strength. When compared with the surface of the SF2 specimen with a fiber content of 2%, it looks that certain parts of the fracture surface are less fibrous so that the impact strength is lower than that of the SF4 specimen.

Likewise, SF6 specimen with 6% fiber content, it looks like the fiber distribution is not evenly distributed. This is not due to the uneven distribution of the fibers, but it could be because the fiber content has exceeded the limit so that some fibers lack a matrix and gather in certain parts of the specimen. As a result, the fiber lacks a matrix, so the bond between the fibers and the matrix is less than perfect. As a result, the impact strength of the SF6 specimen is lower than the impact strength of the SF4 specimen.

The fracture surface of 3 samples of alkali-treated specimens, containing 2% (SA2 code), 4% (SA2 code), and 6% (SA6 code) short fiber content is shown in Figure 6. The highest impact strength was obtained in specimens with a fiber content of 2%. But still lower than the specimen without alkali treatment.

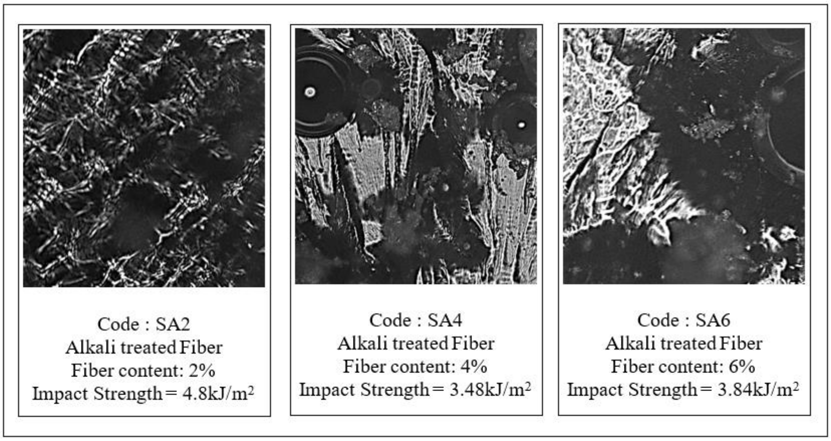

Figure 6: The fracture surface morphology of the impact test specimen composite resin reinforced coconut fiber with alkali treatment. Observations were made using optical microscopy with a magnification of 100x

When viewed from Figure 6, it appears that on the fracture surface of the SA2 specimen with a fiber content of 2%, the fibers are relatively evenly distributed, so that the bond between the fibers and the matrix is evenly distributed, resulting in high impact strength. When compared with the surface of the SA6 specimen with a fiber content of 6%, it appears that there are certain parts of the fracture surface where there is an accumulation of fibers so that the impact strength is lower than that of the SA2 specimen. Because the build-up of fibers will result in some fibers that are not attached to the matrix, meaning that the fibers lack the matrix as a binder. So that the impact strength goes down. The same thing happened to the SA4 specimen with 4% fiber content. The conditions are almost the same as the SA6 specimen. it appears that the fiber distribution is not evenly distributed. This is not due to the uneven distribution of the fibers, but it could be because the fiber content has exceeded the limit so that some fibers lack a matrix and gather in certain parts of the specimen. As a result, the fiber lacks a matrix, so the bond between the fibers and the matrix is less than perfect. As a result, the impact strength of the SA4 specimen is lower than the SA6 specimen.

Conclusion

It can be concluded from this study that:

1. The impact strength and the shear stress of the specimen were obtained in this research. Generally, the untreated fiber has better impact strength and shear strength than the treated one. The highest impact strength, 7.07kJ/m^2 was obtained from the samples containing 4% untreated fibers, whereas the highest shear strength, 1.81 MPa was obtained from samples containing 4% untreated fibers.
2. The impact strength and the shear strength of composite materials in this research are influenced by the fiber contained (%). The regression models were generated to determine the effect of coir coconut fiber content on the mechanical properties (impact strength and shear stress) of resin matrix composite for alkali-treated and untreated fibers as follows:
   a. The impact strength of untreated fibers:
      $y1 = 0.0969x^3 - 1.2367x^2 + 4.8216x + 1.3705$
   b. The impact strength of treated fibers:
      $y1 = 0.1343x^3 – 1.4x^2+3.9782x+1.3705$
   b. The shear strength of untreated fibers:
      $y2 = 0.0427x^3 – 0.2527x^2+0.1133x+0.05$
   c. The shear strength of treated fibers:
      $y2 = 0.0466x^3 – 0.3645x^2+0.7837x+0.05$

The coefficient of determination (R^2) of all the regression equations above is 1. It indicates that the percentage of the fiber content of 100% affects the shear strength of the composite material. These regression models can be used to predict the impact strength and the shear strength of composite material reinforced with a certain content of coir coconut fiber either treated or untreated fiber.

Acknowledgment

This research was supported by Yayasan Menara Bhakti via Research Center (PUSLIT) with contract agreement letter Nomor: 02-5/884/B-SPK/IV/2020 Universitas Mercu Buana, Jakarta. We thank you profusely for the funding support for this research. Hopefully, the results of this research are useful for all.

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