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A Comparison of Tensile and Flexural Properties of Jute Mat Epoxy-Based Composites Treated with Different Alkaline Solutions

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Keywords:

Jute mat; Epoxy resin; Alkali treatment; Mechanical properties.

Highlights:

- *Jute mat/epoxy based laminated composites.*
- *Different alkaline chemical treatments (NaOH, KOH, and LiOH solutions) used for modifing natural fibers surface.*
- *Mechanical tests conducting, such as tensile and flexural tests.*

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Abstract: Each year has seen the high intricacy utilized of natural fiber/polymer-based composites in most engineering sectors due to the good mechanical performance and low cost. In this work, three layers of jute fiber mats were examined as reinforcement for thermosetting-based composite materials prepared by the hand lay-up process. An alkali chemical treatment with different types of solutions (NaOH, KOH, and LiOH) and concentrations (2%, 4%, and 6% wt) was used to treat jute fibers with the point of enhancing the ability of adhesion between the surface of the jute mat and epoxy resin. Various mechanical tests like tensile and flexural have been studied by comparing the results and performance of different types of alkali treatment. The experimental results indicated that alkali treatments were more efficient for flexural behavior than tensile. The highest tensile and bending strengths were shown in the concentration of 6% wt NaOH 31% and 90%, respectively, better than the untreated composite.

مقارنة خواص الشد والانحناء لمادة متراكبة ذات أساس من الايبوكسي مقواة بحصيرة ألياف الجوت المعالج سطحها بالمحاليل القلوية المختلفة

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الخلاصة

تشهد العديد من القطاعات الهندسية الحيوية كل عام زيادة مضطردة في معدل استخدام المواد المركبة ذات الأساس البوليمري المقواة بالألياف الطبيعية لما تملكه من أداء ميكانيكي جيد وتكلفة تصنيع منخفضة. في هذا العمل تم تحضير مادة متراكبة ذات أساس من البوليمرات المتصلدة بالحرارة مقواة بثلاث طبقات من حصيرة الجوت بطريقة الصب اليدوي. لغرض تحسين قابلية الربط بين الألياف وراتنج الايبوكسي. تمت معالجة أسطح ألياف حصيرة الجوت بمحاليل قلوية مختلفة (محلول هيدروكسيد الصوديوم NaOH ومحلول هيدروكسيد البوتاسيوم KOH ومحلول هيدروكسيد الليثيوم LiOH) وبتراكيز وزنية مختلفة (٢٪ و ٤٪ و ٦٪ نسبة وزنية). تمت دراسة الاختبارات الميكانيكية مثل الشد والانحناء لمقارنة النتائج وأداء المعالجة الكيمياوية بالمحاليل القلوية المختلفة. بينت النتائج العملية التي تم الحصول عليها الى ان المعالجة الكيمياوية بالمحاليل القلوية الثلاث اكثر فعالية على سلوك الانحناء مقارنة بسلوك الشد. تم الحصول على أعظم مقاومة شد ومقاومة انحناء للمواد المتراكبة المعالجة بمحلول هيدروكسيد الصوديوم بتركيز وزني ٦ % أفضل بمقدار ٣١٪ و٩٠٪ على التوالي مقارنة بتلك المقواة بألياف غير معالجة.

الكلمات الدالة: حصيرة الجوت ، راتنج الايبوكسي ، المعالجة بالمحاليل القلوية، الخواص الميكانيكية.

1.INTRODUCTION

Recently, using natural fibers with polymeric composite systems has been widely accepted as a promising alternative to synthetic and traditional fibers due to its many advantages. A great advantage of natural fibers is that they are recyclable and biodegradable [1, 2]. Natural fibers also have other benefits for composite fabrication, i.e., light, low cost, ease of preparation, availability, specific strength properties, and eco-friendly materials [3-6]. Due to their advantages, natural fibers reinforced polymer-based composites should be utilized in vital sectors like sporting equipment, automobiles, marine structures, construction, aerospace components, and biomedical and household applications [7-10]. On the other hand, the major drawback that limits their usage is poor interfacial properties or incompatibility with various common types of thermoplastics and thermosetting matrices due to several reasons, i.e., their smooth surface and hydrophilic nature of natural fiber and hydrophobic behavior of polymer matrix material [11, 12]. Various surface modifications of natural fibers have been shown to enhance the adhesion with polymeric-based materials. Alkali treatment, acetylation, benzoylation treatment, and silane treatment are the famous successful chemical techniques to modify the natural fibers surfaces [13]. Strong solutions, such as sodium hydroxide (Table 1), are used to treat alkali to form important modifications in the chemical composition, microstructure, fiber wettability, and load transferability; thereby, they modify the performance of natural fibers used in a wide range of composite industries. Epoxy resin is a popular thermoset polymer widely used as a matrix material for manufacturing natural fiber composites, such as hemp fiber composites [15], date palm fiber composites [16], flax fiber composites [17], okra fiber composites [18], sisal fiber composites [19], and kenaf fiber composites [20]. It possesses many characteristics, such as lightweight, mechanically strong, good thermal and electrical insulation, resistance to moisture and corrosion, relatively low cost, higher dimensional stability, and cures at room temperature without pressure [21-23].

Table 1 The Chemical Surface Treatment with NaOH Solution of Most Common Natural Fibers [14].

Fiber	NaOH (%)	Soaking time	Soaking ternperature CC)	Dryng
Hemp	10 or 15	15 or 45 min	160 or 180	80˚C for 48 h
Jute	Up to 28	30 min	20	-
Ramie	15	2 h	-	-
Henequen	2	1 h	25	60˚C for 24 h
Curaua	10	-	-	-
Flax	1, 2, 3	20 min	Room Temperature	80˚C for 48 h
Kenaf	3, 6, 9	3 h	Room Temperature	Room Temperature for 48 h
Sisal	2	4 h	60	80˚C 24 h
PALF	5	30 min	-	60˚C for 24 h
Bagasse	1, 3, 5	2 h	25	70˚C for 72 h
Piassava	10	-	Room Temperature	-
Oil palm	0.5, 1, 2, 4	-	-	70˚C, until constant weight
Coir	5	48 h	-	-
Kenaf	6	48 h	19±2	110˚C for 5 h
Henequen	2	1 h	25	60˚C for 24 h
Hemp	6	48 h	20±2	60˚C for 48 h
Jute	5	4 and 24 h	25	80˚C, until constant weight
Sisal	10	1 h	-	-
Coir	2	1 h	70	70˚C, until constant weight
Jute	2	1 h	70	70˚C, until constant weight
Hemp	0.8-8	48 h	20±2	-

In this work, three kinds and concentrations of alkali treatment, including NaOH, KOH, and LiOH solutions, were applied in an attempt to get better mechanical performance by comparing the tensile and flexural test results of jute mat-epoxy laminated system before and after the alkali treatment.

2.EXPERIMENTAL PROGRAM

2.1.Materials and Methods

The jute mat was obtained from a local supermarket (Baghdad, Iraq). Epoxy resin and hardener system (Sikadur®- 52 - Egypt) were provided by a local laboratory for chemical suppliers (Baghdad, Iraq).

2.2.Alkali Surface Treatment

Three alkali aqueous solutions were used for surface treatment of jute fibers: NaOH, KOH, and LiOH. Concentrations of 2%, 4%, and 6% of each alkali solution were chosen. The alkali treatment was accomplished at room temperature for 1 hour as the immersion time of jute mat fibers. The fibers were washed several times with distilled water directly after the alkali treatment was achieved to remove the excess of alkaline adhered on the fiber surface and then dried for one day at room temperature.

2.3.Laminated Composite Samples Preparation

Samples of jute mat/epoxy-based laminated composites were manufactured by a double-faced mold using a hand lay-up technique. The epoxy resin and hardener were mixed thoroughly at 33% weight basis of hardener and 67% epoxy resin. Three layers of treated and untreated jute fiber were impregnated with the epoxy resin/hardener mixture and then added to the mold. The excess amount of the resin mixture was expelled upon squeezing the mold using OHD paper. All composite specimens were cured at room temperature for 24 hours. The conditions of different alkali treatments of prepared laminated composite samples are shown in Table 2. The symbols N, K, and L mean NaOH, KOH, and LiOH, respectively, and the number represents the percentage concentrations of solutions.

2.4.Laminated Composite Samples Preparation

After manufacturing, the laminated composite samples were machined with an automatic dumbbell-shaped sample machine, LYDS-250, for tensile and bending tests according to ISO 527 [24] and ISO 178 [25], respectively. The tensile lamented composite samples were with dimensions of 150 mm × 20 mm × 4mm (Fig. 1). The size of the bending samples was 80 mm × 10 mm × 10 mm, as presented in Fig. 2. Each test was conducted using a universal testing machine (LARYEE, China). The bending strength of jute mat laminate composites was calculated using Eq. (1):

$$\sigma = 3FL/(2bd^2) \quad (1)$$

Table 2 Condition of Alkali Surface Treatment.

Name of samples	Alkali treatment	Concentration (%)	Time (hours)
N1	NaOH	2	1
N2	NaOH	4	1
N3	NaOH	6	1
K1	KOH	2	1
K2	KOH	4	1
K3	KOH	6	1
L1	LiOH	2	1
L2	LiOH	4	1
L3	LiOH	6	1

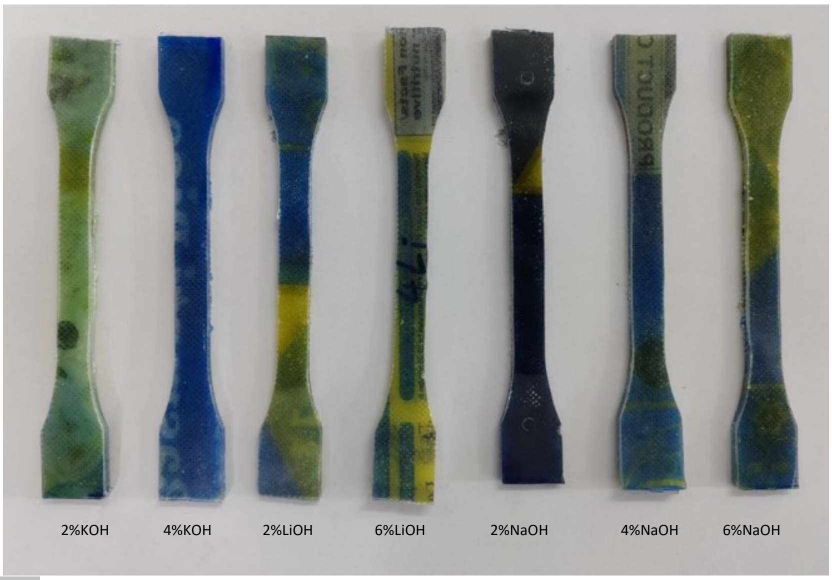

Fig. 1 Jute Mat Epoxy Laminated Composite Tensile Selected Test Samples.

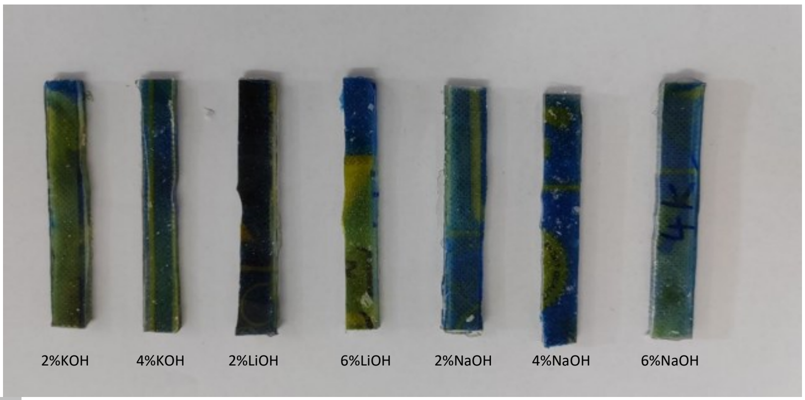

Fig. 2 Jute Mat Epoxy Laminated Composite Bending Selected Test Samples.

3.RESULTS AND DISCUSSION

3.1.Tensile Test Results

The tensile test results revealed that the strength of composites was improved following all alkali treatments compared to untreated composites. The untreated natural fiber composited showed a tensile strength of 22.29 MPa. Figures 3 to 5 show the tensile strength of jute epoxy systems treated with 2%, 4%, and 6% concentrations of NaOH, KOH, and LiOH, respectively. Observations showed that the tensile strength of all treated composite samples increased with the solution concentrations. For each type of alkali treatment, the highest tensile strengths of 29.1, 27.8, and 28.6 MPa were obtained in the N3, K3, and L3 composite conditions, respectively. By comparing the tensile strength values of the three alkali treatments, the best results were obtained by NaOH conditions, as shown in Fig. 6. The sodium hydroxide treatment further modified the tensile strength of composites than lithium hydroxide and potassium hydroxide alkali treatments of all concentrations used. A slight increase in tensile strength values with 4% and 6% NaOH concentrations was obtained. About 1.93%, 4%, 4.1%, and 1.6% increase than for the laminate samples treated with KOH and LiOH solutions, respectively. Furthermore, it has been observed that decreasing the NaOH concentration resulted in higher improvements in the tensile strength values of laminated composite samples. About 15.8% and 9.2% increased in tensile strength of samples treated with 2% NaOH compared to the samples treated with the same concentrations of KOH and LiOH solutions, respectively.

3.2. Bending Test Results

The bending strength results of all treated composites are shown in Figs. 7 to 9. The impact of all three alkali treatments on the flexural properties of composites was similar to the tensile test results. The composites' bending strength values increased with the solution concentration percentage. The experimental results indicated that the bending strength of composites by NaOH, LiOH, and LiOH treatment conditions gave better results than untreated composite conditions. The concentration of 6%wt alkali treatments of composite conditions N3, L3, and K3 gave the maximum bending strength values of 71.2 MPa compared to the untreated composite condition of 37.4 MPa. On the other hand, the flexural test results showed that the composites by NaOH treatment improved than the other types of alkali treatment, as indicated in Fig. 10.

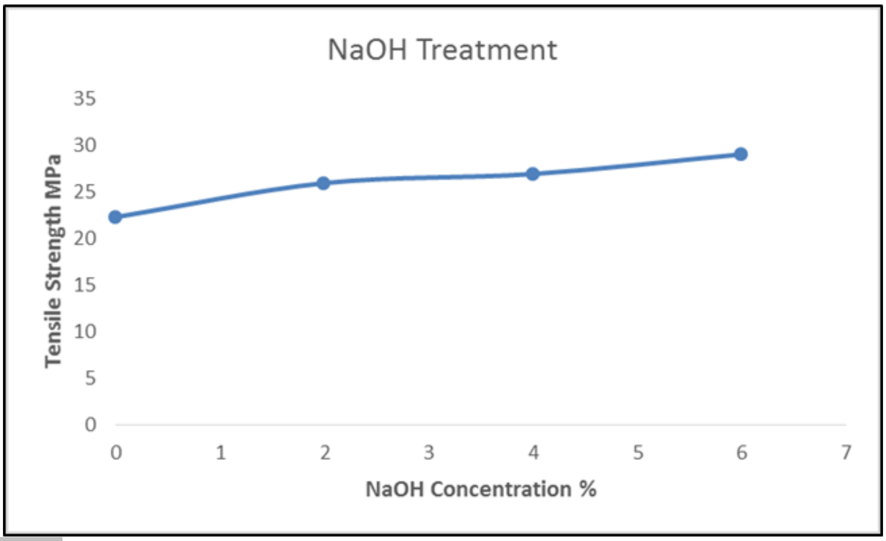

Fig. 3 Influence of Increasing NaOH Concentration on the Tensile Strength of Jute Mat/Epoxy-Based Composites.

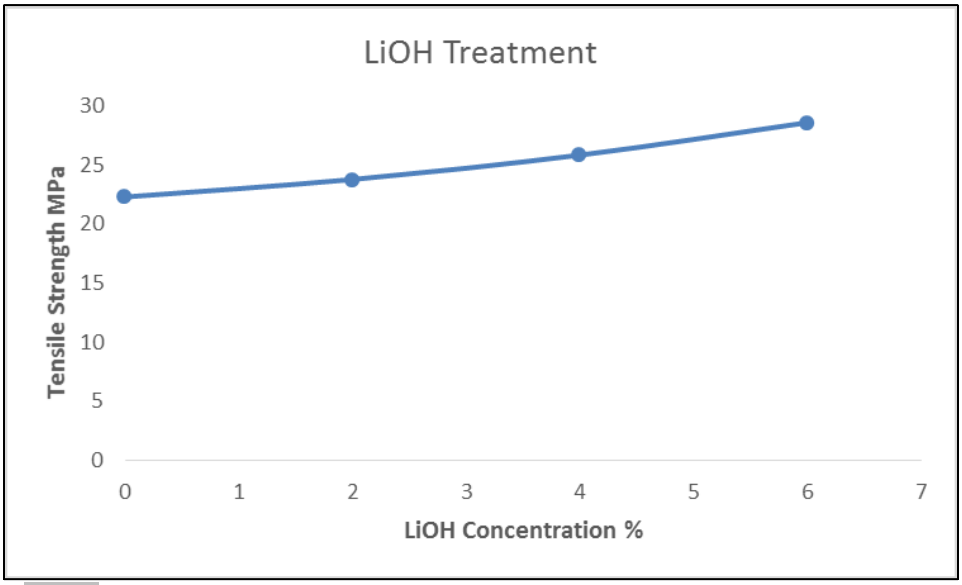

Fig. 4 Influence of Increasing LiOH Concentration on the Tensile Strength of Jute Mat/Epoxy-Based Composites.

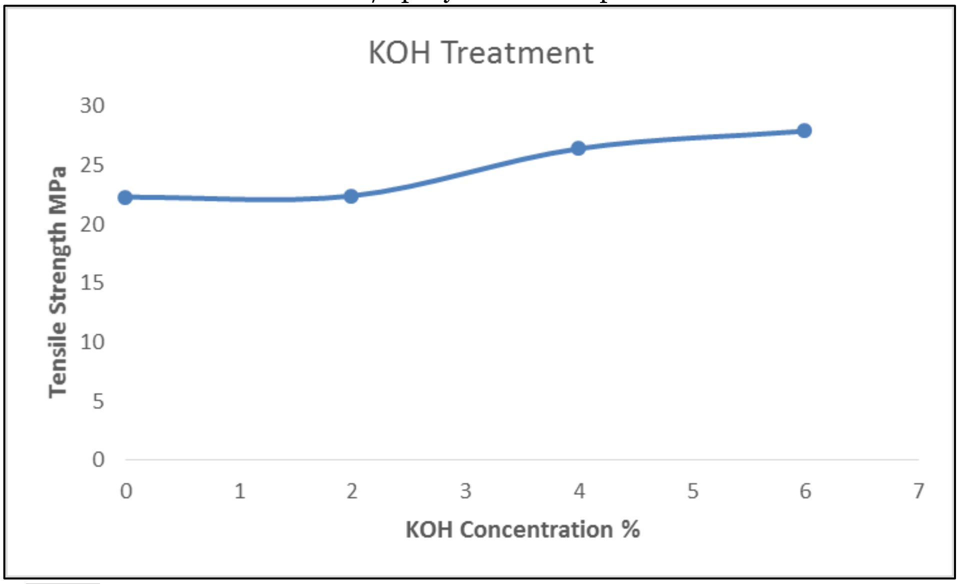

Fig. 5 Influence of Increasing KOH Concentration on the Tensile Strength of Jute Mat/Epoxy-Based Composites.

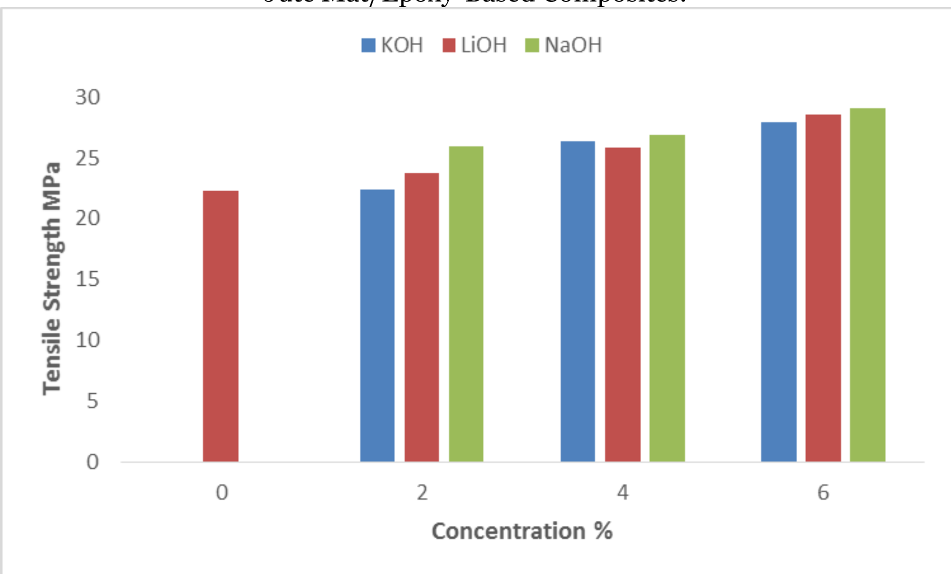

Fig. 6 Variation of Tensile Strength of Jute Mat/Epoxy-Based Composites under Various Conditions of Alkali Treatments.

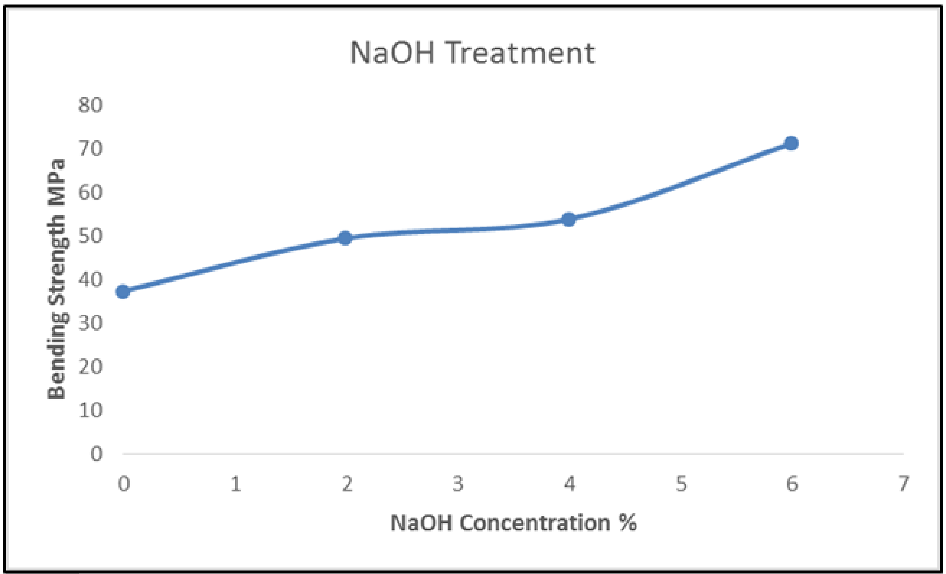

Fig. 7 Influence of Increasing NaOH Concentration on the Bending Strength of Jute Mat/Epoxy-Based Composites.

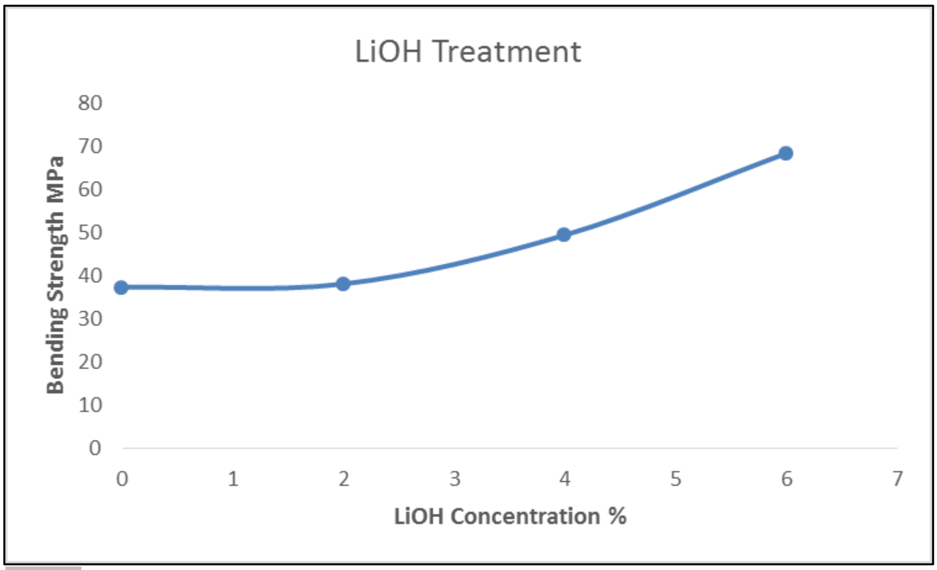

Fig. 8 Influence of Increasing LiOH Concentration on the Bending Strength of Jute Mat/Epoxy-Based Composites.

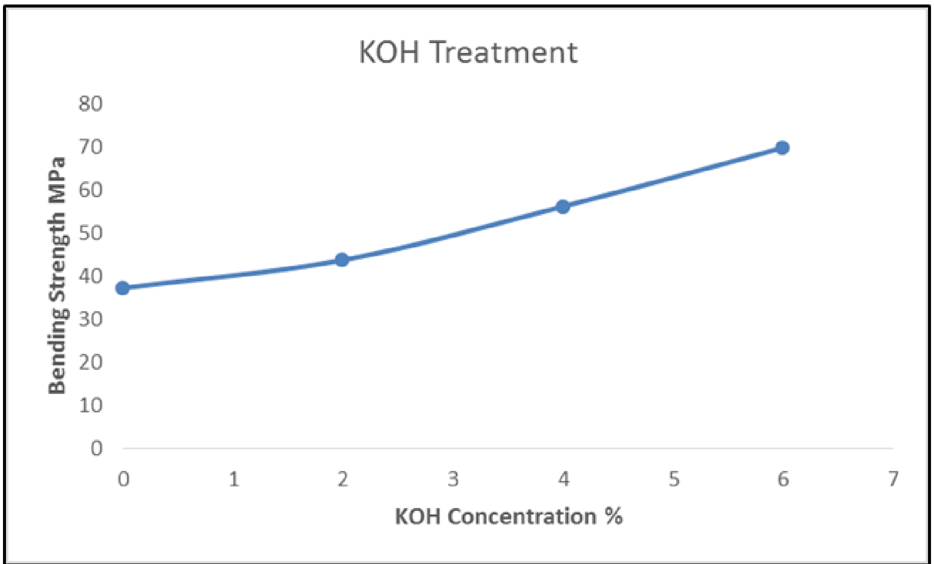

Fig. 9 Influence of Increasing KOH Concentration on the Bending Strength of Jute Mat/Epoxy-Based Composites.

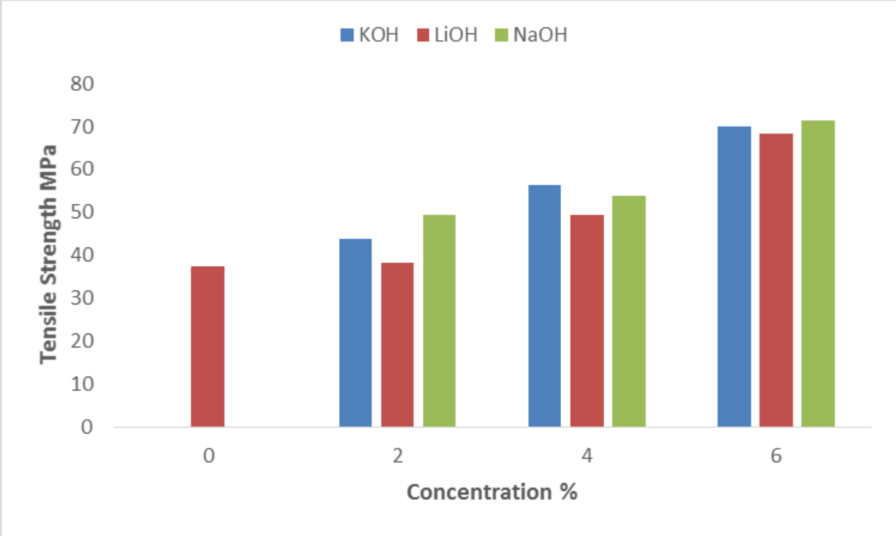

Fig. 10 Variation of Bending Strength of Jute Mat/Epoxy-Based Composites under Various Conditions of Alkali Treatments.

The specific performance of different alkaline solution treatments NaOH, LiOH, and KOH was modifying the natural fiber surfaces by enhancing the matrix-fiber bond. Then, it reflected on the mechanical properties of the jute mat compared to untreated composite for several reasons: the first is related to the reduction of the OH groups of fiber, as follows [26-28]:

$$\boldsymbol{Fiber - OH + NaOH \rightarrow Fiber - O - Na - H_2O} \quad \textbf{(2)}$$

The second reason is that the alkaline treatment eliminated the composite's water adsorption by improving the bond characteristics of the fiber surface and hence increasing the surface area, which enhanced mechanical properties [29, 30]. The third reason is that the chemical composition of natural fibers during the chemical treatment is altered via partial decomposition of hemicelluloses and lignin, increasing the fiber surface roughness and resulting in better mechanical performance of the result composites [31-33].

4.CONCLUSIONS

The main conclusions of the present research work could be summarized as follows:

- The effect of different alkali surface treatments of jute mat on the mechanical properties of jute mat/epoxy-based laminated composites was investigated. The NaOH, LiOH, and KOH concentrations of 2% wt, 4% wt, and 6% wt were used to treat the jute mat improved tensile and flexural strengths compared to the untreated composite.
- All types of alkali treatment performed better on bending strength than composites' tensile strength.
- Among the three alkali treatments, the NaOH treatment showed comparatively the best mechanical performance, while the KOH treatment showed the lowest improvement in performance.
- A composite treated with 6% wt NaOH solution had the highest tensile and bending strengths compared to untreated composite, i.e., composites by LiOH and KOH treatments.

The highest tensile and bending strengths were shown in the concentration of 6% wt NaOH, respectively, 31% and 90% better than the untreated composite.

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NOMENCLATURE

F	The bending load, N
L	Span length, mm
b	Width of the sample, mm
d	Thichness of the sample, mm
	Greek symbols
σ	Bending strength, MPa

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