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Effect of nanoclay (Kaolinite) on mechanical properties of epoxy-fiber composite

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ABSTRACT

An experimental investigation using drag-out tensile test to calculate the interfacial shear strength for different embedded lengths of Kevlar and carbon fibers reinforced epoxy matrix with nanoclay (kaolinite) for different ratio weight, the interfacial shear strength increased by with increasing of embedded length and ratio weight fraction of nanoclay that adding to epoxy matrix.

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تأثير مادة الطين النانوي (Kaolinite) على الخصائص الميكانيكية لمركب الألياف الإيبوكسي

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جامعة القادسية، كلية التربية، قسم الفيزياء، القادسية ، العراق

الـــخُـــلاصـــة

تم استخدام فحص السحب الليف المنفرد لحساب قوة القص البيني لمتراكب ايبوكسي فايبر و لعدة الياف مغمورة من الكاربون والكفلر وبتعزيز لمصفوفة الايبوكسي من خلال اضافة نسب وزنية من النانوكلاي (كاولينيت)الى المصفوفة وذلك لحساب الخواص الميكانيكية ودراسة تأثير الاضافات في المصفوفة على قوة القص البيني وكذلك زيادة طول الليف المغمور وتأثيره في قوة التلاصق بين المصفوفة والليف .

الكلمات المفتاحية:

كاولينيت
فحص السحب
قوة القص البيني
الياف الكاربون
الياف الكفلر

1. INTRODUCTION

The efficiency of fiber-reinforced composites is often controlled by the properties of the fiber-matrix interface Good interfacial bonding or perfect adhesion, to ensure load transfer from matrix to reinforced fiber, is a primary requirement for effective use of reinforcement properties a fundamental understanding interfacial properties and quantitative characterization of interfacial adhesion strength can help in evaluating the mechanical behavior and capabilities of composite materials [1,3]. A large number of analytical techniques have been developed for understanding interfacial adhesion of Kevlar and carbon fibers reinforced epoxy matrix such as drag-out adhesion test of U-shaped single fiber specimen, the interfacial shear strength which interfacial parameter calculated used by Kelly-Tyson-analytical model [4]. Drag-out micromechanical test of U-shaped specimen [4].To measure the maximum drag-out force or peak force from force-displacement curve by S.Nuriel [1]. By adding kaolinite as nanocly to the epoxy matrix for increasing the bond between fiber and matrix due to increasing the interfacial shear strength at the interface[5]

2. THEORY

One of the more important tests is dragging out and using to calculate peak force with displacement to get interfacial shear strength this test, the theory was putting by Nuriel model The drag out use a form of U-shape for testing, that sample has a free length and tow embedded A force is applied at appoint on free length in the direction normal to fibers as in figure(1) A hook applies a tensile $l_1$and l_2 from the left (A)and the right (B)edge (H) is a distance normally to baseline (AB) this force causes attention (T) that exerts to debond the fiber from matrix.

Fig.(1): Shows pulling fiber during test

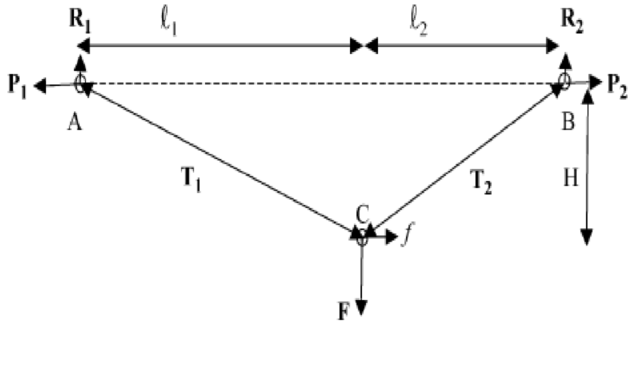

Fig.(2): Dragging out test

In dragging out that described in figure (2) as follow:

$$P_1 = P_2 = f \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

$$F = R_1 + R_2 \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

From torque, we balance we get

$$R_1 L_1 = R_2 L_2 + fH \dots\dots\dots\dots\dots (3)$$

$$R_1 = R_2 = \frac{F}{2} \dots\dots\dots\dots\dots\dots (4)$$

$$P_1 = P_2 = \frac{F}{2}\frac{l_{1/2}}{H} \dots\dots\dots (5)$$

$$\sqrt{H^2 + l_1^2} = l_1\left(1 + \frac{T_1}{AE}\right) \dots\dots\dots\dots\dots\dots (6)$$

$$\sqrt{H^2 + l_2^2} = l_2\left(1 + \frac{T_2}{AE}\right) \dots\dots\dots\dots\dots\dots (7)$$

The right–hand sides arise from the geometry, and the left side from Hooks law A is the fiber cross-section and E is Young's model.

If $l_1 = l_2 = l_{1/2}$

$$F = \frac{2AE}{l_{1/2}}\left(1 - \frac{l_{1/2}}{\sqrt{H^2 + l_{1/2}^2}}\right) \dots\dots\dots\dots\dots\dots (8)$$

$$P = \frac{F}{2}\frac{l_{1/2}}{H} = AE\left(1 - \frac{l_{1/2}}{\sqrt{H^2 + l_{1/2}^2}}\right) \dots\dots (9)$$

Table (1): mechanical properties of Kevlar fiber

Kevlar fiber	Properties
Diameter mm	003

Elongation%	٣
Density g/cm^3	1٤٤
Modulus of elasticity	130
tensile strength Mpa	4100

Table (2): mechanical properties for polypropylene fiber

Polypropylene fiber	Properties
Diameter mm	003
Elongation%	23
Density g/cm^3	092
Modulus of elasticity	28
tensile strength Mpa	2300

Table(3): The properties epoxy(6)

Properties	Value
form	Low viscosity liquid
Density	11kg/lit
Volume solids	100%solvent free
Mix ratio	A: B 2:1 by weight
Viscosity	Normal/20C°300mpa
Compressive strength	44Mpa/20C°
Tensile strength	22Mpa
Colour	Mixed pale straw coloration
Application temperature	(5-35)C° normal
Modulus elasticity	5

Table(4): properties of nanoclay powder particles

Properties	Value
Molecular formula	[$Al_2Sio_2O_5(OH)_4$]
Molecular weight	2582g/ml
Appearance	White powder
PH	40-60
Aps	<80nm
Specific gravity	~ 26
Melting point	>1500 C°
Solubility	Insoluble in cold water

3. EXPERIMENTAL PROCEDURE

Kevlar ,polypropylene fiber/epoxy/ nanoclay are the nanostructured U-shape specimens used in this study The resin polymer used as a matrix is low viscosity epoxy (SIKADUR/52) with two parts, part A (Resin) and part B (Hardener) [6]. The nanoclay particles used nanokaolinite$Al_2Si_2O_5(OH)_4$,

80nm, six U-specimens matrices of different weight fraction used are (0,1,3,5,7,12) wt %, each specimen matrix has been reinforced once using kevlar fiber and once again using polypropylene fiber with diameter 0.03 µm.

4. SPECIMEN PREPARATION

For preparation matrix resin, the nano kaolinite particles with different weight fraction are mixed by ultrasonic stirrer with epoxy resin (part A) for 90 min [2]and then the mixture is stirred slowly with the hardener (part B) for 10 min, the nanoclay epoxy polymer poured in U-shaped polysiloxane specimen Figure (1) Where the Kevlar or,polypropylene fibers with embedded lengths of(3,4,5) mm have been fixed The U-shaped specimens were cured for a week at room temperature,by using tensile test by (Microcomputer Controlled electronic Testing machine model ESM301).

Fig. (3) A. Polysiloxane U-shaped mold

Specimen l_e mm		Pure 0%	1 %	3 %	5 %	7 %	12 %
Polypropylene fiber $3L_e$mm	Peak force N	١١٩.	١.٢٩	٣.٣٥٥	٢.١٩	١.٢٩	١.٠٤
	Distance mm(H)	٢.٤٤	٢.٥٨	٥.٨٥٨	١٢.٩٦	٩.٥٢٨	٦.٩١١٨
Polypropylene fiber $4L_e$mm	Peak force N	٠.٣٧٨٣	١.٠٤٥	٣.٦٣	٣.٥٤	٢.٥٦	١.٥٢
	Distance mm(H)	١٠.٤٣٤	١٤.٨	١٠.٨٦٢	١١.٣١	٩.٠١٨	٩.٠٦
Polypropylene fiber $5L_e$mm	Peak force N	٥٩٧.	١.١٢٥	٣.٨٣٥	٢.٨٢	٢.١٤٥	٢.١٤
	Distance mm(H)	١٢.٠٠٢	٧.٧٧٥	١٢.٧٧٥	١٥.٩٨	٩.٥٦	١.٠٠
	Distance mm(H)	١١٩.	١.٢٩	٣.٣٥٥	٢.١٩	١.٢٩	١.٠٤

Fig (3) B. U-shaped drag-out specimen

5. RESULT AND DISCUSSION

The force vs displacement curves from a drag-out test of specimens shown in Figure(4),(5).

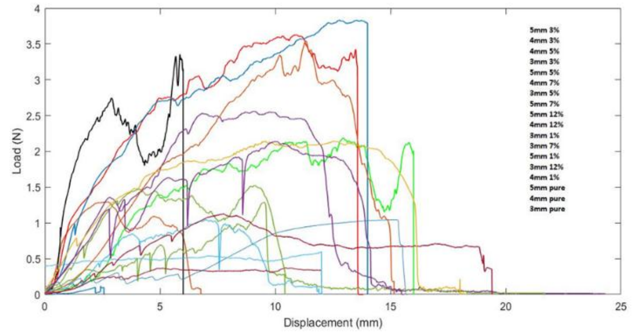

Fig.(4) Descending order of maximum load (N) for polypropylene fiber with different embedded length reinforced epoxy nano-clay.

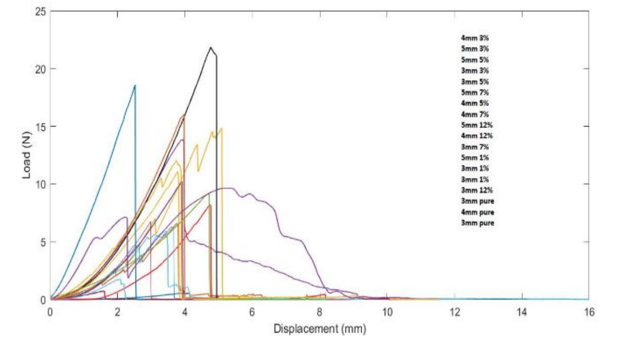

Fig (5) Descending order of maximum load (N) for Kevlar fiber with different embedded length reinforced epoxy nano-clay.

From figure (4), (5) calculate peak force vs displacement shown in table(4),(5)

Table(4):Maximum Force(N)calculated from figures between force versus displacement for polypropylene fiber.

Table(5): Maximum Force(N)calculated from figures between force versus displacement for kevlar fiber.

Specimen l_e mm		Pure 0%	1 %	3 %	5 %	7 %	12 %
Kevlar fiber $3L_e$mm	Peak force N	0551	658	1485	1385	82	592
	Distance mm(H)	3876	375	3167	392	747	345

Kevlar fiber $4L_e$mm	Peak force N	0732	630	2184	1108	1023	92
	Distance mm(H)	1602	36	4764	378	3909	470
Kevlar fiber $5L_e$mm	Peak force N	179	676	1857	1602	1203	965
	Distance mm(H)	2072	279	252	3966	374	535
	Distance mm(H)	244	258	5858	1296	2928	6918

From table (4),(5) calculated the shear force from equation (9) for each specimen and tablet, because that had to left and write a component that was equal to each other using one component to calculate shear force at drag out the test.

Table (6): shear force (N) calculated by equation(9)

Specimen $L_e$mm	Pure 0%	%١	%٣	%٥	%٧	%١٢
Carbon fiber $3L_e$	19421	45641	159984	52821	46811	33058
Carbon fiber $4L_e$	14210	95646	135037	125803	95882	48221
Carbon fiber $5L_e$	34860	42414	56351	78356	74147	28729
Kevlar fiber 3Le	12576	155091	413280	312403	152906	152376
Kevlar fiber 4Le	30290	116101	303975	194402	173486	129651
Kevlar fiber5Le	45815	120465	390910	214285	170293	95515

From table(6) calculated maximum interfacial shear stress at failure from equation (10)from S Nuriel [1].

$$t = \frac{P}{\xi l_e} \dots\dots\dots\dots\dots (10)$$

where(t) the maximum average interfacial shear stress at failure ξ is the fiber perimeter, l_e embedded length, P is force shear.

Table (7): Maximum interfacial shear stress at failure

Specimen/($L_e$mm)	Pure	%١	%٣	%٥	%٧	%١٢
Carbon fiber $3L_e$	05493	12909	4525	1494	1324	0935
Carbon fiber $4L_e$	05359	3607	50925	47443	36159	18185
Carbon fiber $5L_e$	16433	19994	26564	36937	34953	13543
Kevlar fiber 3Le	03557	43866	116892	8836	43248	43098
Kevlar fiber 4Le	11423	43784	114635	73313	65425	48894

Kevlar fiber 5Le	21597	56787	184275	101014	80276	45026

The interfacial shear strength increased when adding of nanoclay to epoxy in adding of nanoclay in1% the adhesion increasing and interfacial shear strength with each one because of d-space is decreasing (non-crystal)for consideration epoxy is crosslink In a 3% ratio weight of nanoclay –epoxy represented a higher value of in interfacial shear strength because of regulating in layers that lead to increasing bonding to a matrix (epoxy–nanocaly) that is mean van der Waals or hydrogen bond(strong bonds),after 3% ratio the interfacial shear strength decrease because of aggregate regulating in layers that lead to weak bonds When the surface area of the fiber increase that is to mean the adhesion area between fiber and matrix increase (perfect adhesion) but there is some abnormal behavior in samples The interfacial shear strength increase when increasing the diameter that can be explained this adhesion between the fiber and the matrix is imperfect adhesion for several reasons due to the presence of bubbles between fiber and matrix or fiber-containing filaments.

6. CONCLUSION

- The increasing in the embedded length of the fiber which leads to increased adhesion between fiber and matrix or fiber-containing filaments
- Drag-out test is more flexible than pull-out and microbond tests .
- using nanoclay for increasing interfacial shear strength in matrix leads to perfect adhesion
- Preparation methods for specimens allow the matrix to be in phase-separated, intercalated or exfoliated structure.
- For matrix with 3 wt% nano clay the interfacial shear strength at fiber-matrix bonding strength was sufficiently hig.

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