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Comparative Study on the Creep Behavior of a Hybrid Composite Material Doped with Nano Material

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Abstract—Today, we are facing a technological revolution in the improvement of engineering materials where it is required to produce a specific material with relatively high strength associated with lightweight to be used in many industrial applications, so the core idea behind this investigative study is enhancing creep strain property for a specific composite material composed of carbon fiber plus epoxy resin mixed with hardener. The improvement procedure was done by adding additive material named multi-wall carbon nanotubes (MWCNTs), where the mixing style was a percentage weight base. The total suggested weight was 1 Kg for both cases, where the reference composite was composed of one kilogram of carbon fiber plus epoxy resin with hardener. Meanwhile, the second composite consists of the above-mentioned components (0.9 Kg) with multi-wall carbon nanotubes (0.1Kg). Final experimental results showed the average percentage creep strain for the reference is 0.19566, and the associated value for the hybrid one is 0.173 with a reduction in creep strength resistance of about 11.58% under 120 hours of continuous loading of weight 5 kilograms under 25°C in both two cases. Scanning electron microscopy showed that the internal undesired gaps with the reference composite have been totally recovered due to adding the nanomaterial with the suggested percentage ratio, making the produced composite more challenging and sustaining dimension changes during ordinary loading.

***Keywords*—Creep behavior; hybrid composites; nanomaterials; MWCNTs; mechanical properties.**

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I. INTRODUCTION

In the last few decades, engineering materials have faced rapid enhancement, especially with the massive need for materials with comparatively high strength and adequate low specific weight. This is because of the broad spectrum of advanced applications that consider different boundary conditions, particularly with climate change and the associated high levels of temperature increment around the globe [1], [2]. In other words, engineering components must sustain an applied load under mainly increased ambient temperature levels and keep their original properties and overall dimensions; this phenomenon is highly placed in most polymers, including polymeric composites where such modern substances are commonly used today and at the same time it is suffering from two essential factors, they are firstly loading time duration and secondly the ambient or working temperature [3].

Thus, it is necessary to deeply examine the behavior of such materials under a long time of static loading under previously stated room temperature. In other engineering words, this dependable property with these two factors is called creep, where this property is sometimes called time-dependent strain [4]. It is very common in many materials with ductile behavior where, in many cases, such industrial materials exhibit permanent deformation due to their weight only without any applied external loads. This undesired property is very specified and determined in most composite components in our daily lives, where it is required to manufacture a sustainable component with stable dimensions and sustain the external load under the direct effect of the ambient boundary conditions, including temperature fluctuation [5].

Therefore, the main goal behind this research paper is how to improve the creep behavior of composite structure material before and after adding some specific additive materials named nanomaterial and checking the mutual experimental interaction between the period of loading time and the associated induced strain for both pure composite and hybrid one the doped with nanomaterial. Creep is considered a fundamental property in engineering material design, and this unique mechanical test gives a clear idea about the behavior of the materials under examination. In many situations, permanent deformation occurs in a long-time loaded condition, even under this substance's specified yield or ultimate stress [6]. Hence, it is better to show graphically the relation between loading time and the companion extension or increment of the sample under investigation dimensions, especially variation in the longitudinal length–uniaxial extension. In addition, there is a sole difference between the classical tensile test and the creep test, where the first one is an independent process, and the measured mechanical property is entirely independent of the loading period.

Meanwhile, checkup time plays a vital role in the case of creeping until reaching permanent or plastic deformation [7], [8]. This study will shed light on the first phase, named primary phase creep, for the nominated composite material and the associated hybrid supported with nanomaterial. Figure 2 below focuses on the time duration of loading on the horizontal axis and the induced creep strain on the vertical one, and it is so clear that there are two regions. The first one is the so-called elastic region with full recovery after removing the applied load, where there is a plastic zone with permanent deformation even after removing the applied stress.

II. Materials and Method

A. Carbon Fiber

Recently, carbon fiber has been widely used in many miscellaneous applications due to its excellent properties, including high strength and lightweight. These properties are why this material is nominated in this research paper. Figure 1 below shows a macroscopic view within this carbon fiber. The intersectional entanglement among its orthogonal fibers is clear, and it gives mutual support in all directions [9], [10].

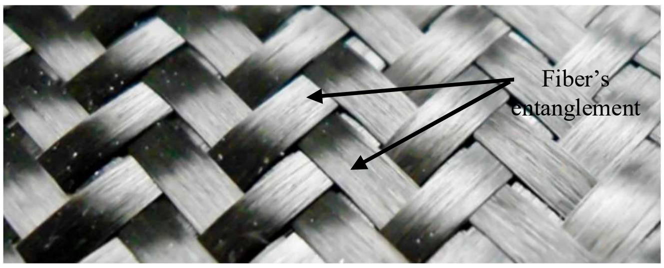

Fig. 1 Carbon fiber macroscopic view

Table 1 summarizes the leading mechanical and physical properties of carbon fiber of grade TC33-6K to be formally considered in this research paper [11], [12].

TABLE I
MAIN MECHANICAL AND PHYSICAL PROPERTIES OF CARBON FIBER

Maximum Tensile Strength GPa	**Young's Modulus GPa**	**Elongation to Failure (%)**	**Strain (%)**	**Poisson Ratio**
3.800	225	~1.55	~2	~0.25
	Density Kg/m3	Fiber Diameter (μm)	Thickness mm	
	~1750	~5	0.20	

B. Multi Wall Carbon Nano Tubes MWCNTs

Previous investigations into the available so-called nanomaterials and their recorded advantages and direct effect on the mechanical properties of engineering materials have selected wall carbon nanotubes as an additive material for improving at least creep tensile strength and the other associated properties (see Figure 2). Tables 2 and 3 summarize multi-wall carbon nanotubes' main and essential mechanical and physical properties [13].

Fig. 2 MWCNTs powder

TABLE II
PRINCIPAL MECHANICAL PROPERTIES OF MWCNTS

Maximum Tensile Strength MPa	Young's Modulus MPa	Thermal Conductivity (W/m.°C)	Surface Area M2/gm
56	**~2.329**	**1500 - 3000**	**250 - 300**

TABLE III
MAIN PHYSICAL PROPERTIES OF MWCNTs

Density Kg/m3	**Inner Diameter (nm)**	**Outer Diameter (nm)**
~2300	5 - 10	10 - 30
Length (μm)	Purity (wt. %)	Color
~5 - 20	≥ 95	Black

C. Epoxy Resin

Producing composite material requires some binding substance, so the best one is epoxy resin, usually called epoxy resin. It is available as a thick liquid, crystal clear, excellent gloss, instantaneous self-leveling without bubble formation, no associated odor, quick cure, and relatively low viscosity with accepted solidity. Plus, it is very comfortable to use wood, Glass, plastic, metals, and acrylic [14], [15]; see Figure 3.

Fig. 3 The employed epoxy resin

Table 4 shows the principal properties of the epoxy resin employed for the experimental part of this research article [16].

TABLE IV
PRINCIPAL PROPERTIES OF THE EMPLOYED EPOXY RESIN

Average Tensile Strength MPa	**Bending Strength MPa**	**Density MPa**	**Viscosity MPa.sec**
74	120	1100	1110
Pressure Strength MPa	Modulus of Elasticity MPa	Deformation Strain (%)	Color
120	2.9 – 3.2	5 - 7	Crystal clear

Such epoxy resin requires another specific material that acts as a catalyst factor, a hardener, mixed with the epoxy resin with pre-defined mixing ratios. See Figure 4, which shows a photo of the selected hardener.

Fig. 4 The employed hardener

In addition, Table 5 below displays the most helpful properties of the counted hardener to be considered in the practical part of this investigative work [17].

TABLE V
PRINCIPAL PROPERTIES OF THE EMPLOYED HARDENER

Specific Gravity 1.02 ±0.1	**Density (kg/m3)**	**Viscosity at 25°C Mpa.sec**
74	980	600
Pot Life at 25°C (min)	Gel Time at 25°C (hour)	Color
30 ±10	24 - 36	Clear

D. Creep Test

As mentioned above, the creep test gives a clear idea about the strength properties of the assigned specimen material. According to the American Standard for Testing and Materials ASTM—D2990 [18], [19]. This test was done for the following specimen dimensions, as shown in Figure 5.

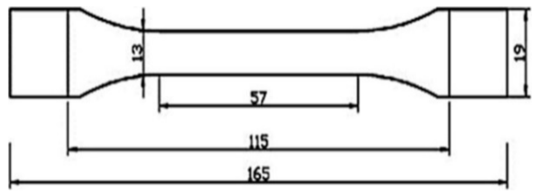

Fig. 5 The standard creep test specimen ASTM-D2990

E. Scanning Electron Microscope

For getting an experimental clear idea about the microstructure of different engineering materials, including composite structures, scanning electron microscope SEM is a very active method for that purpose where it provides images of the morphology of the material under investigation, so it will be easy to introduce a trusted explanation about this material behavior and the associated occurred phenomena. Therefore, the employed one is of type SEM-MIRA-2 model, [20], [21] see Figure 6 gives main capabilities of it.

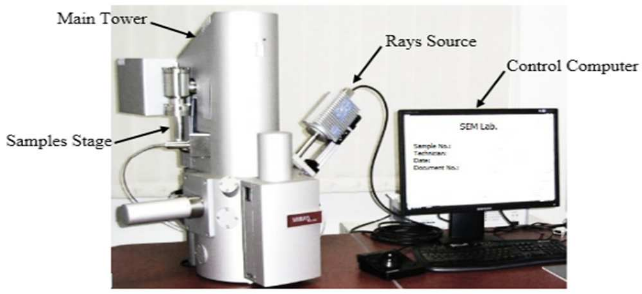

Fig. 6 The adopted scanning electron microscopy system

F. Manufactured Creep Test Machine

Figure 7 shows the only device manufactured within our laboratory: the creep test machine for conducting all creep experimental part tests. It consists of a rigid metallic base, vertical column, suspended horizontal beam, two leading in-line jaws, dial gauge, different precise weights (masses), stopwatch, adjustable hook for fixing weights, and supportive accessories, plus the specimens produced per the ASTM-D2990 [22], [23].

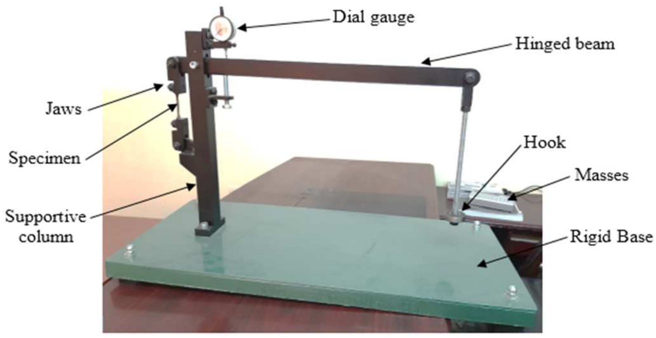

Fig. 7 The manufactured and used creep test machine

III. Results and Discussion

A. Carbon Fiber and MWCNTs Mixing Ratio

The suggested mixing ratio depends on the percentage weight base style. As indicated in Table 11 below, two leading composites are under investigation.

TABLE VI
MAIN PROPOSED TWO COMPOSITES

Composite Name	Composition	Additive Weight (% wt.)
Reference	Epoxy Resin + Carbon Fiber + Hardener	0
Hybrid	Epoxy Resin + Carbon Fiber + Hardener + MWCNTs	10

In other words, the total weights of carbon fibers and the associated weight of MWCNTs are indicated in Table 7 below, where the total produced weights in both cases with and without additive nanomaterial are 1 kilogram.

TABLE VII
MAIN PROPOSED TWO COMPOSITES

Carbon Fiber (%wt.)	MWCNTs (%wt.)	Weight of Carbon Fiber (Kg)	Weight of MWCNTs (Kg)	Gross Weight of the Composite (Kg)
100	0	1	0	1
90	10	0.9	0.1	1

B. Creep Test Results

After preparing creep test specimens with a total length of 165 mm and effective length of 57 mm for both the reference and the hybrid composites according to the ASTM-D2990, [24], [25]. where the constant applied load was 49.05 N at a constant ambient temperature of 25°C, and the observation time reached 140 hours, with recording a result as a creep strain every 6 hours, so the obtained results will be divided into two parts, the first part is for the reference composite [26] as shown in Figure 8.

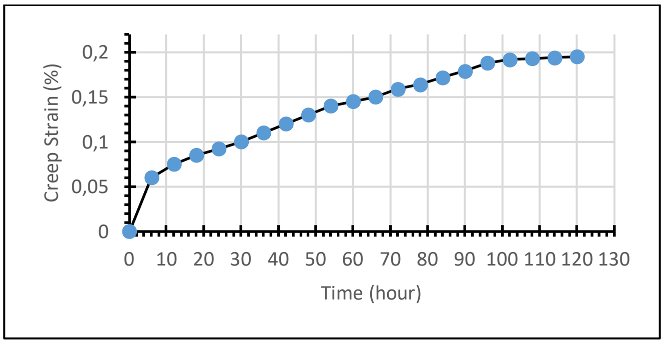

Fig. 8 Creep test for the reference composite

The above three graphs clearly show that the maximum creep strain values as percentage ratios for the reference composite (R) are 0.195, 0.195, and 0.197 at the end of 120 hours of loading according to the applied boundary conditions; therefore, the mean value is 0.19566%. The second essential part is conducting the same experimental test but for the hybrid composite with three repetitions and under the same presented boundary conditions; the results gained are shown in Figure 9.

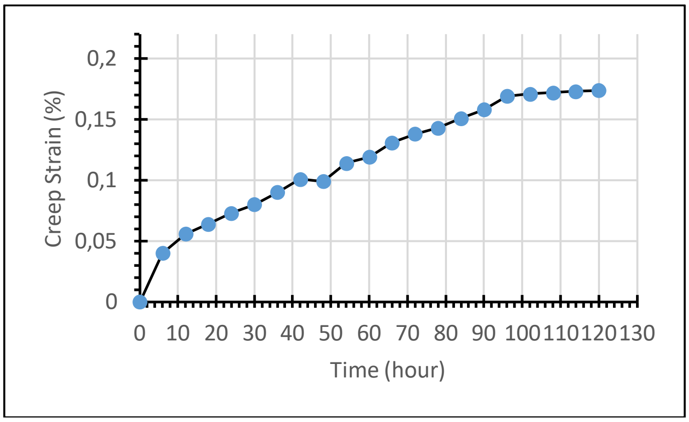

Fig. 9 The creep test for the hybrid composite

The results obtained for the developed hybrid composite (H) are relatively different from those for reference one. The maximum creep strains as percentage ratios were 0.172, 0.173, and 0.174 for the first, second, and third attempts under the same boundary conditions, and the associated mean value is 0.173% after 120 hours of continuous loading time. The calculated difference between the two cases is 0.02266% (reduction ratio of 11.58%). In other words, Figure 10 gives a local difference between any two successive gained results in both cases with and without additive material.

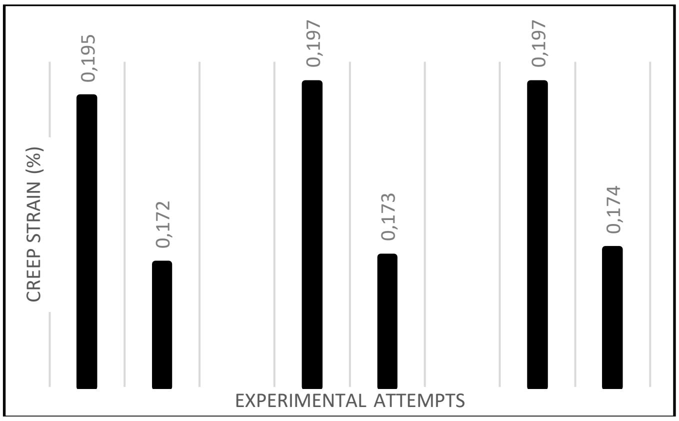

Fig. 10 Comparison between the six attempts of creep tests for the reference and hybrid composites, respectively

C. Morphology Imaging Results

Scanning the microstructure of fibers gives an indication about layering and delayering of the substance under consideration and consequently shows the induced dislocation within the structure before and after adding the additive material, so the reference composite has been checked by using this specific practical examination test [27], [29], [30], [31] as shown in Figures 11, wherein part (a), the microstructure is very clear. The formed layers face some longitudinal spaces as gaps along with the longest axis of the employed fibers [32], [33]. Therefore, such undesired spaces cause some weakness and relatively transform the produced structure into semi-ductile material, which gives a significant creep extension during the total span of the loading time duration, so this phenomenon is considered a disadvantage in such composites. Therefore, the core idea behind this comparative study is how to overcome this property or, in other words, trying to add nano material – Multi Wall Carbon Nano Tubes MWCNTs as an additive where it is expected to gain some finite limit of brittleness for the developed hybrid composite material. where the additive material filled up [34], [35]. The previously mentioned longitudinal gaps make the structure solid and free of spaces and other types of point and lattice defects. The gained structure is much more authoritarian enough and gives a creep resistance under the same boundary conditions where the mean value for the reference was 0.19566%. The opposite value for the hybrid was 0.173%, so the gained reduction in ductility is about (-11.58%), where the minus sign refers to a reduction in the maximum creep strain as a percentage ratio.

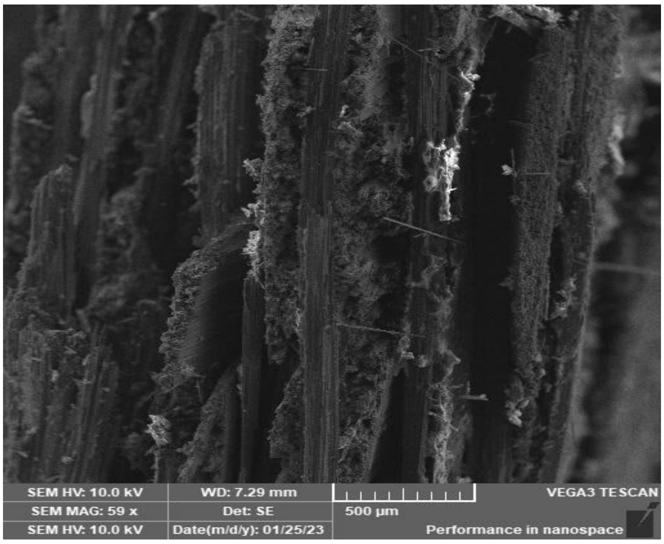

Fig. 11 SEM for both reference and hybrid composites

IV. Conclusion

Based on the above experimental investigation, the following conclusions may be drawn as listed in the following essential points. Using only carbon fibers with epoxy resin shows a relatively flexible composite with high rates of creep strain values under specific finite boundary conditions of direct loading. Adding multi-wall carbon nanotubes as an additive material to a carbon fiber composite is a relatively increasing brittleness of the produced composite material. The vacuum bagging method removes all bubbles in the cast structure, forcing the nanomaterials to occupy the longitudinal spaces. Therefore, this process makes the manufactured composite a solid structure free of flaws or local dislocations. Mixing multi-wall carbon nanotubes with the employed epoxy resin gives an entirely homogeneous mixture under the stated boundary conditions.

Homogeneity helps form an accepted composite material with a moderate level of ductility, which aids in manufacturing different components. It is possible to express the percentage value of the employed additive material in the mixing procedure as a function of the produced composite mechanical property; in other words, the amount of the nanomaterial is directly proportional to the induced creep strain percentage values but with the suggested mixing ratio. The strength of the hybrid composite after adding nanomaterial has been improved compared with the reference one, where the obtained reduction in ductility was about 11.58%. but keeping approximately the same total weight of the composite means a significant increment in the strength ratio to the weight with an accepted value.

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