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RESEARCH ARTICLE

LEVERAGE OF CIGARETTE ASH POWDER CONCENTRATIONS ON THE ALTERNATING BENDING FATIGUE OF UNSATURATED POLYESTER RESIN

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Abstract

The present work, describes an attempt was made to study the effect of cigarette ash powder concentration, on the micro hardness and alternative bending fatigue behavior of unsaturated polyester resin reinforced with various weight fractions of cigarette ash powder (1.25, 3.7, 4.9 Wt. %), which is natural fibers form. The preparation of the composites was achieved using hand lay-up process. During the test, fatigue tests were used by applying a stress ratio sinusoidal wave ($R = -1$), which is believed to give a marginal increase in temperature. The effects of the fatigue life of the test composites are determined using the stress curves (S) number of cycles (N) (S - N). The results showed that the fatigue life of the composite being produced depends on the percentage of fractions of weight. This findings also shows an increase in fatigue age by four times longer for the weight fraction of (1.25 wt. %) and more than two for cigarette ash powder (3.7 wt. %). The higher weight fraction (4.9 wt. %) of cigarette ash powder, reduced the fatigue life lower than the matrix behavior. Increasing percentage weights of cigarette ash powder increases the toughness measured by hardness for all composites.

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Introduction:-

Composite materials are important industrial materials that used in the construction and design of aircraft and spacecraft over the last 30 years [1]. It has been used in many engineering applications when specific strength, resistance to corrosion, high modulus, good fracture and lightness fatigue are required [2, 3]. Composite studies have shown that new materials have been discovered, such as composites of metal matrixes, composites of ceramic matrixes and composites of polymers, many of which have been found to be effective substitutes compared to old materials used in many industrial applications[4]. Reinforced polymeric materials from natural fillers (fibers or particulates) provide materials engineers with a new range of materials that deliver exceptional combinations of mechanical properties that make them equal to steel applications. Applications of polymeric materials as a matrix with ceramics, polymeric materials or alloys had led to the production of composites with an unusual combination used in the industries [5, 6].

The properties of composites are influenced by a number of parameters, including the strength of the bonds between the base material and the supporting materials, the reinforcement phases like the particles, flakes, fibers and the

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distributed supporting materials directions [7, 8]. In the majority of cases, polymer composites were subjected to different types of constant or variable-amplitude fatigue loads during their service life[9]. Polymer composite materials therefore need to demonstrate superior static mechanical properties combined with excellent fracture and fatigue resistance [10].

Fatigue phenomenon is characterized by repetitive loading failure, which causes and spreads cracks as the loading cycles increase. These types of loading can be constant, variable, uniaxial or multiaxial. The cyclic (fatigue) load rate required to cause failure is often lower than the quasi-static maximum load, making it a significant parameter to be considered during design. Synthesis, analysis and testing are necessary procedures for the development of a sustainable product[11]. Fatigue damage is a slow process, the production of which depends on the microstructure of the materials when they are subjected to less stress than their ultimate static strength[12]. For homogeneous materials, early cracking also characterizes the fatigue behaviour, which governs the development of damage and contributes to the final fracture. With inhomogeneous materials, such as fiber or particulate-reinforced polymers, early fatigue damage is often diffuse in nature, as cracks can be caused from many places. The dominant crack cannot be evident in this case until it's really close to the final fracture [13, 14].

In-service fatigue loadings are frequently exposed to mechanical structures resulting in damage to nucleation and propagation; in metal parts, a single crack usually grows with cycle evolution beginning from structural discontinuity, eventually reaching critical dimensions[15, 16].

Composite materials, unlike metals, exhibit a peculiar fatigue behaviour, suffering various types of damage, such as matrix cracking, fibre-matrix de-bonding, fiber breakage, delamination, uniformly distributed across the entire volume of material[17, 18].

The current work tries to research the effect of changing weight fractions (1.25, 3.7, 4.9 Wt. percent) of cigarette ash powder on the mechanical properties of prepared composite materials such as fatigue behavior and shore-D hardness, which are tested at room temperature.

Practical Part:

Raw Materials:

For this study the matrix used was unsaturated polyester (UPE), (SIR Saudi Arabia). It is a viscous liquid type of polymer that is transparent and thermosetting. The liquid converts to solid by adding hardener additives made from methyl-ethyl-ketone-peroxide (MEKP), which are transparent liquid at room temperature for (2%) for each (100gm) of UPE.

The cigarette ash powder was used as a reinforcing material, which was softened by using an electrical mill to obtain a very fine powder (10 - 100 μm).

Specimens Preparation

Composites were developed using hand lay-up (HLU) technique; this method is easy, simple and cheap. The (10 %) liquid UPE blend with MEKP hardener was mixed. The mixture strengthened by cigarette ash powder of specific weight fraction values (1.25, 3.7, 4.9 Wt. %), determined below by Equation (1), [19]:

$$\text{Wt \% of the fibers in the composite} = \frac{\text{Weight of fibers}}{\text{Weight of polyester} + \text{weight of fibers}} \times 100\% \dots(1)$$

The samples were then left for two days to cure, followed by heat treatment in the oven at (55 C^o) for (1 hr.) to complete the polymerization. The entire assembly was then released and allowed to cure at room temperature for (7) days.

After fully cured, the specimens were cut in compliance with the relevant international ASTM standard (HSM20) and (D2240) for bending fatigue and shore-D hardness of the molds with sample measurements (60×10×3 mm), (30×10×3 mm), [20].

Mechanical Tests

Fatigue test

The bending fatigue tests are performed using the system model (HSM20) shown in Figure (1a). It is ideal for alternative bending tests on flat sample bending fatigue, i.e. controlled displacement or controlled strain to assess the prepared sample, which includes pure tension and compression. The fatigue method is carried out at room temperature under constant displacement ($U=10$ mm) to get their number of cycles to failure (N). Testing was performed with a fully reversed bending fatigue measure, then bending stress (σ) versus number of cycle curves (N) was plotted for the prepared composites. The loading type was a sinusoidal wave with a stress ratio of ($R= -1$), [21]. The fatigue loading frequency is set at (10Hz) because there is no proof of thermal softening of any of the samples measured at this frequency, and because the temperature rise does not reach 5 oC, there is no significant heating to (10 Hz)[22].

Hardness test

By analyzing plastic deformation of the material encountered under external stress, the concept of hardness can be taken into consideration. Using Shore-D equipment, as shown in fig. (1b).

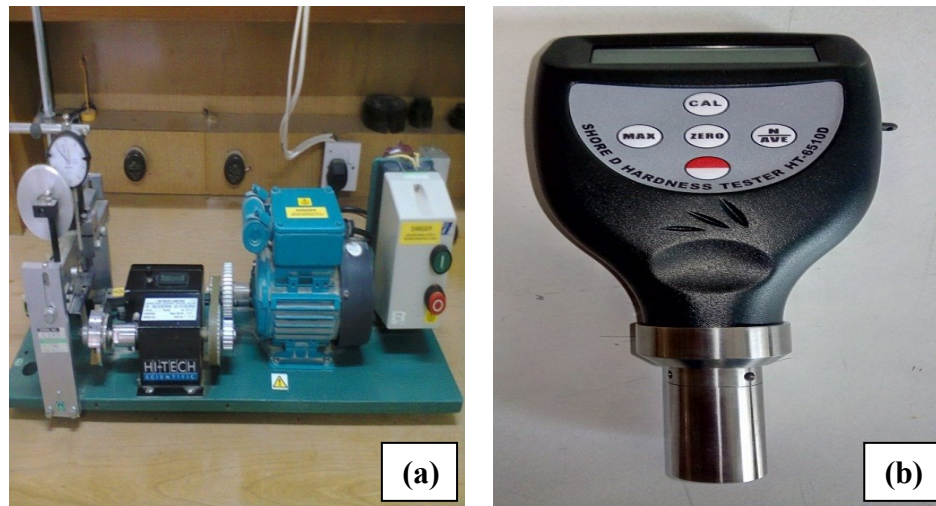


Figure (1):-show a- Bending fatigue machine.b- Shore-D hardness tester.

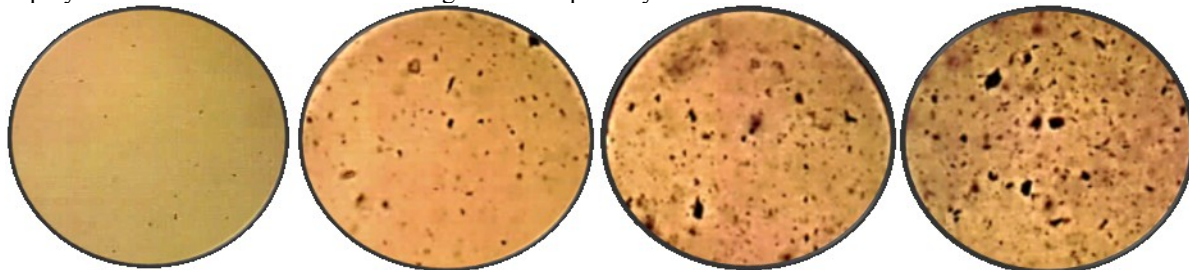
Results and Discussion:-

The study included the effect of reinforcements on mechanical fatigue and Hardness in addition to the optical microstructure before and after samples examination were considered for analysis.

Optical Microstructure:

Figure (2), shows the microscopic examination of the plain base material and polymeric base after adding different weight ratios of the cigarette ash powder.

It appears to be pure, transparent, free from any impurities. After adding different weight ratios (1.25 , 3.7 and 4.9 Wt.%) from the cigarette ash powder. This observation can be referred to the distributing of the reinforcement material which was increased with the increase of the concentration of cigarette ash particles in the prepared samples; also note that increasing the percentage of weights of reinforcement materials led to an increase in the fog of polymeric materials and hence reducing their transparency.



0 Wt.%,100X 1.25 Wt.%,40X3.7 Wt.%,40X 4.9 Wt.%,%,40X
Figure (2):-Microstructure of plain and reinforced with different weight fraction of cigarette ash powder composite.

It is, obvious that, increasing the concentration of the reinforcement material will result an increase in the presence of cigarette ash clusters in random areas of the prepared samples; these clusters can be considered as a fragile areas especially if they occur on the surface of the samples since they increase the cutting of the polymeric chains that are responsible for binding the molecules of the base polymer material, leading to the cracks in the surface as a result of poor binding.

Mechanical Fatigue Examination:

The bending fatigue examination was conducted by (σ -N) curves, which gave a better idea of the material behavior in response to fatigue loading of all specimens prepared.

Figure (3) shows the fatigue curve of the plain and reinforced composites. This plot reveal the influence of the constituents on the fatigue life of these composite. It becomes clear that all used specimens were failed with the applied load levels.

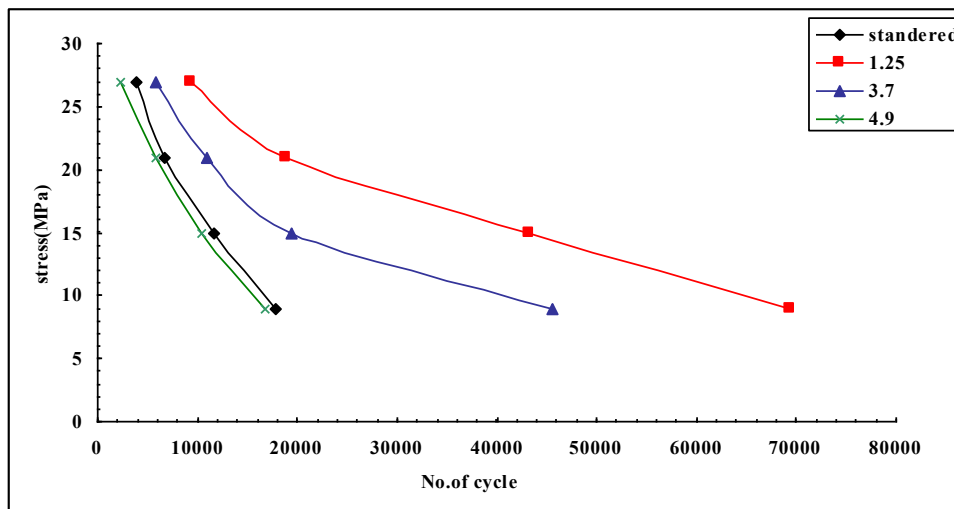


Figure (3):- Fatigue curve of cigarette ash powder composite.

σ -N curves of the unsaturated polyester specimen show a reduction in the first stage and a deterioration in the specimen occurs as a second stage, followed by a fractured specimen at (17844) cycle at (9 MPa). The number of cycles until failure occurs (fatigue age) was improved at the weight percent of (1.25 Wt.% and 3.7 Wt.%) of cigarette ash powder by more than (4 and 2.5) times respectively, in comparison of standard sample at the same level of stress (9 MPa), as shown in table (1).

Table (1):- Fatigue life improvement of cigarette ash powder composite.

Fraction Weight (wt%)	Fatigue strength (MPa)	Fatigue life (No.of cycle)	Times of improvement (X)
0	9	17844	0X
1.25	9	69321	4X
3.7	9	45617	2.5X
4.9	9	16718	-1X

The improvement is due to the plastic region variation of the crack-tip resin / cigarette ash particle contact, which hinders by the existence of a cigarette ash particle perpendicular to the crack direction. The crack must then change its direction of propagation, as shown in Figure (4)[23].

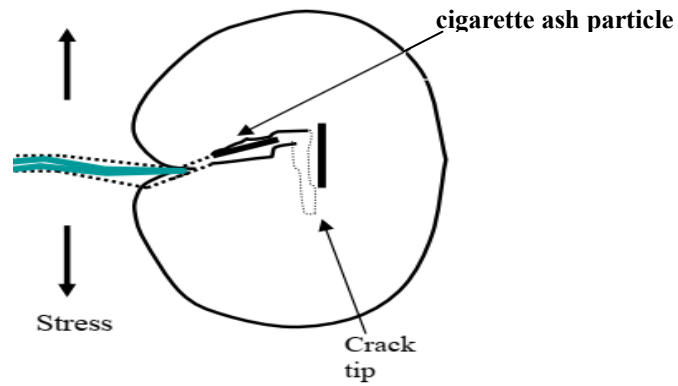


Figure (4):- crack propagation mechanism in resin / cigarette ash particle systems.

As the crack direction changes, the expansion rate is reduced since the present plane of propagation may not be necessarily the plane which experiences the stress level needed for further crack growth [24]. Another explanation is the cigarette ash particles size certainly smaller than the plastic area. This difference cause cigarette ash voids /shear banding that triggers plastic void growth mechanisms [25].

This could be further explained due to the enhancement in fatigue behavior of this composites, where the microscopic examination of the fracture was examined.

when the reinforcement material was (1.25 Wt.%), the fracture surface section of the composite appeared as a semi-ductile type and it does not have sharp edges, although the fracture was concentrated in fragile areas containing the stiffeners, as shown in Figure (5). moreover, figures showed some debris (broken particles), (patches) of cigarette ash particles at the fracture edge.

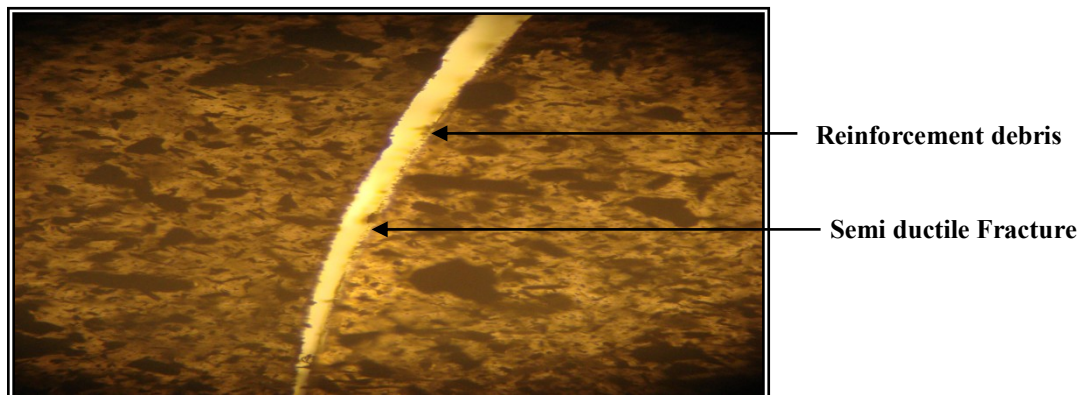


Figure (5):- Fracture section of (1.25 Wt.%) cigarette ash powder composite, 100X.

On the other hand, the increase in the weight fraction of cigarette ash powder to (3.7 Wt.%), the microscopic picture of the fracture section, as in Figure (6), showed sharp edges, which is considered as a feature of brittle fracture. this explains the decrease in the age of the fatigue compared with the age of (1.25 Wt.%) composite.

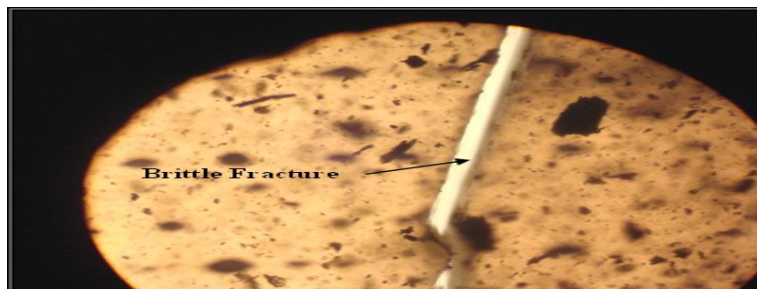


Figure (6):- Fracture section of (3.7 Wt.%) cigarette ash powder composite, 100X.

When the ratio of the cigarette ash powder increased to (4.9 Wt.%), the age of the fatigue decreases below the fatigue age of the plain composites; this is resulted from weak de-bonding between filler and matrix, which means that, not all addition of the cigarette ash powder had improved the fatigue life of unsaturated polyester [26].

A microscopic examination of the fracture section of this composites, as in Figure (7), showed that the fracture become more brittle with increasing of reinforcement material loadings. Hence, fracture surface become more brittle with a sharp edge, which is the reason to earlier failure of the test samples.

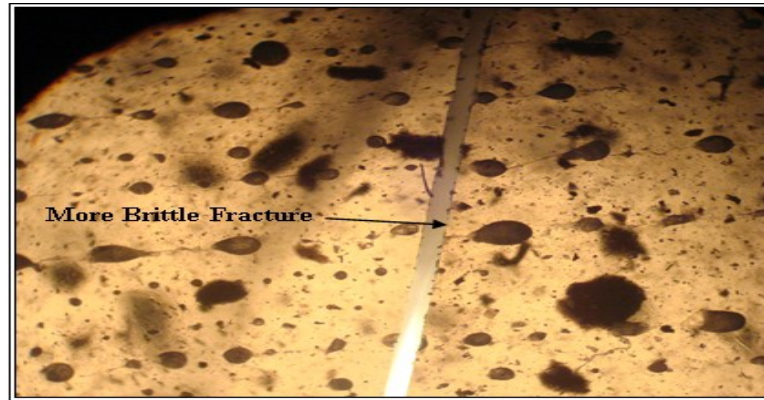


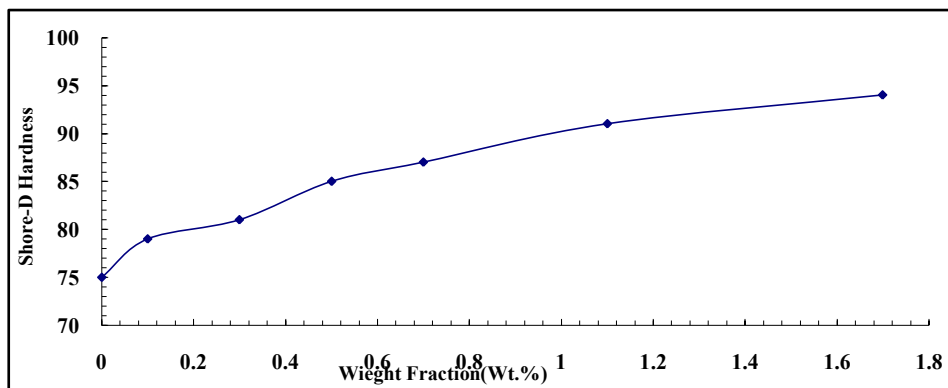
Figure (7):- Fracture section of (4.9 Wt.%) cigarette ash powder composite, 100X.

The process of damage begins with the initiation of micro cracking of the matrix, which is an irreversible micro damage occurring in the strained region at the waist of the test specimen, which is manifested by micro cracking. This could be regarded as a form of failure and is responsible for the subsequent failure mode by the weakening of the particles / matrix bonding and the progressive failure mode called pull out. The low elasticity of the resin can be due to the initiation of micro cracks. Two factors, resin brittleness and interfacial bonding, seem to dominate failure[27].

Hardness Examination:

Hardness is extensively used to characterize materials and to determine if they are suitable for the specific application. The definition of hardness can be counted as an indicator of the material's plastic deformation which may surpass under external stress control [28, 29]. The effect of the percentage of particles added in hardness has been shown in Figure (8). It seems it improves the hardness of unsaturated polyester by cigarette ash particles addition; which increases the resistance to plastic deformation, where the composite materials had the highest percentage value (94) at (4.9Wt. %).

The improvement in microscopic hardness is due to the effect of distribution of cigarette ash particles in the matrix and decreasing the movement of polymer molecular, which lead to distribute the test load on cigarette ash therefore decreases the penetration of test indenter to the surface of fabricated composite material, consequently raise the hardness and increasing of the material strength to plastic deformation [30, 31].



Conclusions:-

The results of this work can be concluded as follows:

1. The addition of specific proportions of cigarette ash powder as (1.25 Wt.%) to unsaturated polyester can contribute to bearing the stresses and reduces the brittle nature of the unsaturated polyester resin which increase the resistance to fatigue, this result strengthening materials, especially the homogeneously distributed.
2. The increase in the weight percent of reinforcement powder to (3.7 Wt.%) participate into the decrease in fatigue life to approximately one third compared to the composite reinforced with (1.25 Wt.%), which was the best compared to the fatigue behavior of the plain substrate.
3. The fatigue life will decrease below the fatigue age of the plain composites, when the ratio of the cigarette ash powder increased to (4.9 Wt.%); this is result of weak de-bonding between filler and matrix, which means that, not all addition of the cigarette ash powder improved the fatigue life of unsaturated polyester.
4. The addition of cigarette ash powder to unsaturated polyester increases the Shore-D hardness.

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