Study the Fatigue Life Prediction of Polymer Matrix-Composite Under Varying Stresses

Mohammed J. Kadhim*1, Hamza M. Kamal2, Zeyad D. Kadhim3
1 Materials Engineering Department, University of Al-Mustansiriyah, Baghdad, Iraq.
*dr.mohammedjkadhim@yahoo.com

Abstract. This study aimed to investigate the defects and techniques of predicting the fatigue life of Nano-polymeric composites structures. This paper provides to studied the fatigue life prediction of polymer matrix reinforced by nano-particles (Nano-ZrO2). The fatigue stress ratio is R = -1. All Samples are usually manufacturing and divided from the mass of polymeric nano-ZrO2 composites. The major property of nano-polmeric composite is depending on the dispersion process of nano ZrO2 in the resin. Specimen surface preparations play an important function in fatigue life. The polymer matrix contain nano-Zirconia will be decrease the brittle fracture of matrix enhance the roughness of the composite surface and the maximum fatigue stress, fatigue life under varying loads. Better fatigue life was done when nano–materials reach to 3% from the total volume of specimen.

Keywords: Fatigue, Particle–Reinforced Composites, Nano-particles. Stress Amplitude.

1. Introduction
Many light duty metal gears and bearings are replaced with reinforced polymer product. It is because of the economical and technical advantages of the polymer composite materials. Polymer composites are generally light in weight and show good resistance to the environment and chemicals. Polymer composites strength and resilience are stronger than classical metals. Due to its low strength and modulus, the polymer composite has limited use in light duty parts despite durability and toughness. In recent studies, Liu et al.[1], Manjunatha et al.[2], Manjunatha et al.[3] and Wetzel et al.[4] Specify ways to improve the strength and rigidity of polymer composites such as combining nano-size clay, short fibers, continuous fibers or nano-particles into the pure matrix. Then, after adding clay, fibers or particles into the matrix, nano-composite becomes a common material. It has 1-100 nm reinforcement size with 10-100 aspect ratio. There have been some interesting observations about the physical degradation of PET, unreinforced fiber samples[5-7]. In addition, Cho et al.[8] The fatigue behavior of unreinforced PET fibers was studied at 104-106 cycles under different processing conditions with the same crystal structure. A more scientific definition for durability is the degree to which a material retains its physical properties while subjected to stress, such as heavy use, or adverse environmental conditions[9]. The reality of polymer matrix composites are a multi-use material can be attributed in large part to the ability of the reinforcement to be adapted to a particular strength specification by controlling the orientation of the fibers and nano-particles contained in the matrix process.[10]. Polymer composites enhanced by nano-materials (nano-composites) and fibers are a popular area of
composite research in science and engineering. Improving the polymeric material properties which can be achieved from proportional to small amounts of nano-particles or from fiber-reinforced materials was a strong motivation for further study, leading to optimistic predictions of greatly improved mechanical properties about polymer materials[11]. Spherical nano-particles and Vapor-Grown Carbon Nano Fibers (VGCNFs), rubber, metallic materials, silica and more recently CNTs and graphene, Glass Fiber (GF), Carbon Fiber (CF), Kevlar Fiber are all strong contenders for polymer matrix reinforcement which positively affect fatigue and crack distribution rates when propagate in epoxy matrices. In the study of the strength of composite materials in specific loading requirements, many researchers examined the strength and durability of the above parameters[12-17]. This research consist to study the fatigue life prediction of nano-polymeric composite under variable stresses.

2. Experimental Work

2.1. Materials

There are several polymers used to produce tensile and fatigue samples these products are made up of Epoxy (Resin and hardener), and nano material (ZrO₂).

2.1.1. Nano materials:
Nano-zircona particles (ZrO₂) as a nano material were used. It has an a approach of high purity (99.9%), and rounded range of particle size (15 to 20 nanometer). The provider of nano-particles is (Sky Spring Company). The properties of nano-ZrO₂ are shown in Table 1.

| Product Name | symbol | purity | particle size | SSA (m²/g) | Color | Bulk Density (g/cm³) |
|--------------|--------|--------|---------------|------------|-------|----------------------|
| Zirconium Oxide | ZrO₂ | 99.9% | 15-20 | 160-180 | white | 2.4 |

2.1.2. Matrix material:
Epoxy resin with its hardener triethylene tetramine (TETA) ratio (3:1) (provided by SIROPOL.GP) is used as a matrix material because of its high strength and modulus, excellent chemical attack, ease of processing and widely available. Furthermore, epoxy resins have been unique to all thermosetting resins due to many factors including low cure reduction, its compatible with a large proportion of polymeric materials, the durable strengthen property, adhesive, corrosion and chemical ability to resist, and insulation property of electricity[18]. The main property of adhesive epoxy resin used in this research is shown in Table 2.

| No. | Mechanical properties of epoxy resin | Value |
|-----|-------------------------------------|-------|
| 1   | Glass transition temperature        | 120 - 130 °C |
| 2   | Tensile strength                    | 60-80 MPa   |
| 3   | Tensile Modulus                     | 3.5-4 GPa   |
| 4   | Elongation at break                 | 0.8%        |
| 5   | Flexural strength                   | 55-65 MPa   |
| 6   | Compressive Strength                | 55-65 MPa   |
2.2. Procedure for Specimen's Preparations:
Using the epoxy resin weight ratio to the hardener, the main specimens were prepared was 3:1. Epoxy nano-particles samples of varying volume fraction (1%, 3%, 5% and 7%) of nano-partials ZrO2. To get better curing conditions, the samples are cast aside for 48 hours before leaving the molds and placed in vacuum chambers for 10 days before any examination. The specimens are shown in Figure 1.

![Figure 1](image1.jpg)

**Figure 1.** Flat specimens of fatigue test.

3. Experimental Tests

3.1. Tensile Test

The tensile properties are measured by a universal testing machine at a strain rate of 10 mm / min based on the ASTM D3039 specification. The data obtained included the tensile strength, the module of elasticity and the break elongation. Figure 2 shows the geometry of the tensile test specimen.

![Figure 2](image2.jpg)

**Figure 2.** Geometry of Tensile Test According to ASTM D3039
3.2. Fatigue test

A fatigue–device of type HI-TECH, the equipment can be used to perform all constant and variable stress fatigue operations as shown in Figure 4. A 2800 rpm motor rotates a specimen through a gear and pulley arrangement between 5600 or 1400 rpm. The applied loads are subjected perpendicular to the axis of samples in the right side. The load applied is represented by (P) and measure unit is Newton (N), the stress (σ) has the measure unit (MPa).

3.3. Hardness Test

HPE II is digitized for decimal accuracy and high usability. While the device itself can store up to 300 measurements, data also can be converted to your personal computer for further processing, evaluation and management of data. The force can be applied evenly to the sample by means of a proprietary pressure grip which is the center of the instrument head. Shore hardness tester can be used for non-destructive testing. The device is shown in Figure 5.
4. Experimental Result
The experimental work's test series were divided into several series (0, 1, 3, 5 and 7 percent). The results of the fatigue tests at constant amplitude of stress are details in Table 3. In these series, many samples have been investigated; they were used to estimate the basic S-N curve (only fatigue) and the prediction life of nano Zircona under constant stress at composite. In these series the samples were investigated and used to estimate the typical S-N curve.

Table 3. The fatigue parameters at a different percentage of nano-ZrO₂ additions.

| Sample | A    | m    | S-N curve eq.       | σE.L. (MPa) | Increase in σE.L.% |
|--------|------|------|---------------------|-------------|-------------------|
| At 0%  | 423.87 | -0.1661 | σf = 423.87Nf -0.1661 | 91.79       | ----              |
| At 1%  | 381.6  | -0.144 | σf = 381.67Nf -0.1443 | 101.03      | 10.06%            |
| At 3%  | 372.483| -0.1258 | σf = 778.483Nf -0.1258 | 116.92      | 27.37%            |
| At 5%  | 401.549| -0.1397 | σf = 504.549Nf -0.1397 | 110.90      | 20.81%            |
| At 7%  | 491.238| -0.1672 | σf = 491.419Nf -0.1672 | 105.31      | 14.72%            |

Table 4. The effect of Nano-Zircona addition on the Fatigue Life Cycles Results.

| Cycles | σf CON. | σf 1% | σf 3% | σf 5% | σf 7% |
|--------|---------|-------|-------|-------|-------|
| 10⁵    | 134.565 | 140.86| 156.20| 152.98| 154.77|
| 10⁴    | 91.79   | 101.03| 116.92| 110.9 | 105.31|
| 10⁵    | 62.62   | 72.47 | 87.51 | 80.39 | 71.66 |

4.1. Nano Zircona Life Prediction:
At the good enough of nano-ZrO₂ content addition to the epoxy matrix, the nano-particles dispersion in the matrix of epoxy is give the better fatigue limit and increased related to the increasing of the nano-ZrO₂ amount reach to 3%. In such cases, the only epoxy matrix was filled with nano-particles which at the lower concentrations, they are of practical’s concern because the addition of nano fillers at high concentrations will impede the manufacture process and so lead to costs increase, at the other
hand, the nano-particles adhere to each other because of the inherent Vander Waals force between the particles resulting in nano-particles agglomerations[19].

**Table 5.** The Results of Damage Under Variable Stresses.

| Specimen No. | Applied stress (MPa) | D7 | D5 | D3 | D1 | D0 |
|--------------|----------------------|----|----|----|----|----|
|              | Low | High |    |    |    |    |    |
| S1           | 45  | 55   | 0.83 | 0.81 | 0.82 | 0.80 | 0.77 |
| S2           | 35  | 45   | 0.75 | 0.78 | 0.79 | 0.77 | 0.76 |
| S3           | 25  | 35   | 0.74 | 0.77 | 0.78 | 0.76 | 0.74 |

**Figure 6.** S.N curve at control samples.

**Figure 7.** S.N curve at 1% nano-ZrO₂ samples.
Figure 8. S.N curve at 3% nano-ZrO\textsubscript{2} samples.

\[ \sigma_f = 778.483 \sigma_f^{0.1256} \]

Figure 9. S.N curve at 5% nano-ZrO\textsubscript{2} samples.

\[ \sigma_f = 504.549 \sigma_f^{0.1397} \]
5. Conclusions
Related to the results that are gained in this examination, it is apparent the nano-ZrO₂ particles are present in the matrix composite of epoxy will be decrease the fragility nature of the epoxy resin; therefore, the maximum fatigue stress amplitude, number of fatigue cycle (fatigue life) and good finished will given better surface roughness of composite materials. Also the best improvement is achieved to the composite that using the strengthen by nano particles (nano-ZrO₂). The best results are found for nano ZrO₂ composite reinforced epoxy resin up to 3%, the surface hardness also increased with nano zircon (nano-ZrO₂) reinforced epoxy resin reach to 3%.
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