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| RESEARCH ARTICLE

Effect of Dilute Sulfuric Acid on Some Mechanical Properties of Polyethylene Reinforced With Silica Nanoparticles

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| ABSTRACT

This research aims to investigate the effect of dilute sulfuric acid absorption on the impact, hardness, and tensile tests of polyethylene reinforced with nanoparticles of silicon oxide ($SiO2$) at volume fractions (1%, 3%, and 5%). Samples were prepared using hand molds. Impact, hardness, and tensile tests were performed for different time periods on the prepared samples. All tests were performed under normal conditions (without immersion) and under immersion using dilute solutions of dilute sulfuric acid (0.2 N) for 5 weeks. The results under normal conditions showed an increase in the impact hardness and tensile values. After immersing the pure polyethylene samples in the chemical solution, a decrease in the impact hardness and tensile test values was observed. However, reinforcing the polyethylene with silica nanoparticles significantly improves its mechanical properties, including tensile strength and impact resistance, especially at moderate volume fractions such as 0.1-0.3. The addition of silica also improves the material's resistance to chemical corrosion, especially when exposed to dilute acids. Furthermore, while mechanical performance naturally declines after prolonged immersion, reinforced composites retain their properties better than unreinforced polyethylene.

| KEYWORDS

polyethylene, Nano- Silica, Reinforcement, dilute sulfuric acid, Absorption

| ARTICLE INFORMATION

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1. Introduction

Polyethylene (PE) is one of the most widely used thermoplastic polymers due to its remarkable combination of chemical resistance, flexibility, mechanical strength, processability, and affordability. It finds significant applications across packaging, construction, consumer goods, and chemical industries. However, while polyethylene generally demonstrates favorable resistance to many chemicals, its stability and durability can be compromised under aggressive chemical environments, such as exposure to strong acids over prolonged periods. Sulfuric acid, a highly corrosive mineral acid, is prevalent in several industrial processes where PE components may be used for storage, containment, or transport (Dorigato et al., 2012). Understanding how dilute sulfuric acid impacts the mechanical properties of PE is therefore crucial for assessing its suitability, especially in applications requiring extended service life under such chemical exposures.

In recent years, the incorporation of nanofillers, particularly silica (SiO_2) nanoparticles, has garnered considerable attention as a strategy for enhancing the mechanical, thermal, and barrier properties of polymers, including polyethylene. The inclusion of silica nanoparticles is known to improve tensile strength, elastic modulus, and sometimes toughness, attributable to both the high surface area of the nanoparticles and their potential to interact favorably with the polymer matrix—assuming adequate dispersion. This has led to the development of polymer nanocomposites with superior properties compared to their neat counterparts. However, relatively less is known about how these nanocomposite materials perform when subjected to harsh chemical conditions, such as dilute sulfuric acid exposure. Understanding the effect of such environments on mechanical properties is vital for the effective design and utilization of silica-reinforced PE nanocomposites in chemically challenging settings (Gültekin, 2022; Selver, 2020).

Several studies have focused on the mechanical reinforcement mechanisms afforded by silica nanoparticles in PE matrices. For instance, Hoseini et al. (2020) demonstrated enhanced tensile and impact properties in high-density polyethylene (HDPE) upon the inclusion of surface-modified silica nanoparticles. Similarly, Meer et al. (2016) analyzed the improvement in barrier properties, attributing it to better filler-matrix adhesion and nanoparticle dispersion. On the chemical resistance front, existing literature offers a broad overview of the response of polyolefins to acidic environments (e.g., Nikam, 2023), often reporting embrittlement, reduction in mechanical strength, or changes in crystallinity after acid exposure. However, these studies largely focus on pristine (unfilled) polyethylene rather than its nanocomposite derivatives.

Research specifically addressing the behavior of polymer nanocomposites, and polyethylene nanocomposites in particular, under acid attack is limited. While some reports suggest that nanofiller addition may enhance acid resistance due to the barrier effect of nanoparticles, others raise concerns that interfaces between nanoparticles and the polymer may serve as pathways for acid ingress or sites for accelerated degradation, especially if the interface bonding is inadequate. For example, a study by Palza et al. (2016) observed that while nanofillers can slow down the diffusion of certain chemicals, inadequate dispersion or agglomeration may lead to localized weaknesses under chemical stress. Furthermore, many of these studies lack systematic mechanical property evaluations post chemical exposure and rarely address the influence of acid concentration, exposure time, or nanoparticle loading in a comprehensive manner.

From the foregoing, it is evident that while the mechanical property enhancement of PE via silica nanoparticle reinforcement is well established under inert conditions, there remains a critical knowledge gap regarding how dilute sulfuric acid affects the mechanical integrity of these materials, and whether the presence of silica nanoparticles serves as a mitigating or exacerbating factor (Ragupathy et al., 2023). This gap is significant because the interaction between acidic media and the polymer-nanoparticle interface is complex and may impact long-term service performance.

Therefore, the scientific problem addressed by this study is to systematically investigate the effect of dilute sulfuric acid exposure on key mechanical properties—such as tensile strength, modulus, and elongation at break—of silica-reinforced polyethylene nanocomposites, in comparison to neat polyethylene. By elucidating the role of nanoparticle loading and exposure conditions, this research aims to advance understanding of the chemical-mechanical interplay in polymer nanocomposites under acidic environments.

From the author's perspective, while advances in nanocomposite technology promise extended applications of PE in harsher chemical settings, the real-world performance of these materials—especially under long-term acid exposure—has not been adequately validated. Most prior works have prioritized mechanical enhancement or acid resistance in isolation without considering the synergistic or antagonistic effects of nanoparticle inclusion in aggressive environments. There thus exists a pressing need for focused studies that marry mechanical property measurements with rigorous chemical exposure protocols in order to provide data-driven recommendations for material selection, formulation, and application.

2. Materials and Methods

Low-density polyethylene (LLDPE) reinforced with silica nanoparticles (SiO2) at a concentration of (1%, 3%, and

5%) was used. Mechanical tests were conducted on pure polyethylene and polyethylene reinforced with silica nanoparticles at different concentrations (1%, 3%, and 5%) before and after immersion in an acidic solution such as dilute sulfuric acid ($H2SO4$) at a concentration of (0.2M).

2.1 Specimens Preparation

Pure polyethylene samples reinforced with silica nanoparticles were prepared according to standard dimensions for impact testing using a Charpy apparatus. The samples were then immersed in a dilute sulfuric acid solution (0.2M) for 1, 3, and 5 weeks. After the immersion period, changes in impact hardness (Shore D), tensile strength, and tensile strength were measured.

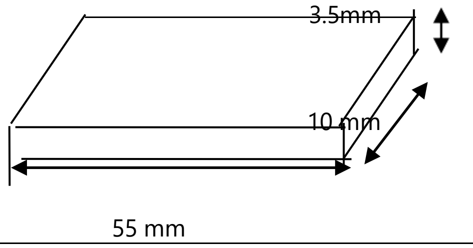
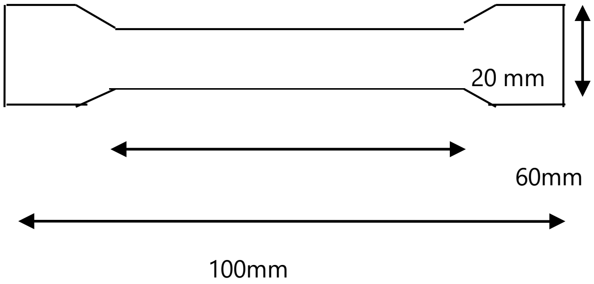
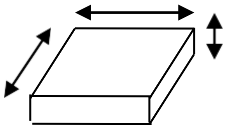
Standard System	**Standard Specimen Dimensions**	**Test Type**
ISO-179		**Impact**
ASTM D-638-78		**tension**
ASTM- D2240	**10 mm** **3.5 mm** **10 mm** 	**hardness**

Figure (1): Standard dimensions of examination specimens

2.2 Cutting the samples:

We cut the samples using an electric saw with very fine, sharp teeth to ensure they do not shake during the cutting process. We then smoothed the edges of the cut samples with sandpaper. The samples were cut to appropriate dimensions according to the American Standard for Tensile Testing (ASTM-ISO-179) and Impact and Hardness Testing.

2.3 Mechanical Tests

1- Impact Test
2- Hardness Test
3- Tensile Test

2.4 Equipment Used

A set of devices for mechanical and physical testing of pre-prepared samples was used. The following is a review of the most important of these devices and some illustrative photographs.

2.5 Impact Test Instrument

This research used an impact testing device with an alpendicular structure, the parts of which are shown in Figure (1), using the Charpy Impact Test method manufactured by the American company (Testing Machine Inc., Amityville, New York). The Garbi and Izod tests rely on the use of pendulum-type devices that have a breaking energy greater than the energy required to break the specimen under test. This involves allowing a pendulum of known weight to fall from a height (h0) to hit the specimen at its lowest point in its path. The height (h) is then measured, which is the height reached by the pendulum after hitting the specimen and represents a measure of the breaking energy. If the energy is high, the loss will be large, and vice versa. We divide the energy required for breaking (E_c) by the cross-sectional area (A) of the specimen to obtain the fracture toughness value. Therefore, it can be said that a material with a high breaking energy has high toughness [3]. The device consists of a pendulum in which a hammer is fixed for breaking the specimens. The device contains hammers of different sizes with energies (2, 5, 30, 45), respectively. One hammer can be replaced with another, depending on the energy required for breaking. However, the testing speed is constant for all hammers, which is (3.42 m/sec). The pendulum touches the other end of the indicator, which moves on the special scales to calculate the energy expended for breaking, which is fixed on the panel of the device. At the beginning of the test, the pendulum is raised with the hammer upwards so that it is fixed by means of fixing in the device, and the sample is placed on the two supports of the device, and the distance between the two supports is 40 mm. When the pendulum is released, the potential energy of the pendulum is converted into kinetic energy when it hits the sample so that part of the kinetic energy is lost in breaking the sample, and the measuring indicator reads the value of the energy of breaking.

Figure 2: The shock resistance testing device.

2.6. Hardness Test Instrument

The Shore D Durometer Hardness Tester, manufactured by TIME GROUP INC., was used to conduct the hardness test. This device features a point-penetrating tool. The point-penetrating tool is inserted into the surface of the material by applying pressure to the device (ensuring that the tool is fully in contact with the sample surface). The process is repeated several times (3-5) in different locations on the sample surface to take into account factors affecting the accuracy of the reading, such as the homogeneity and smoothness of the sample surface and its freedom from impurities and gaps. The average of these readings is taken to determine the hardness value of the material's surface, which represents a measure of the degree of surface indentation.

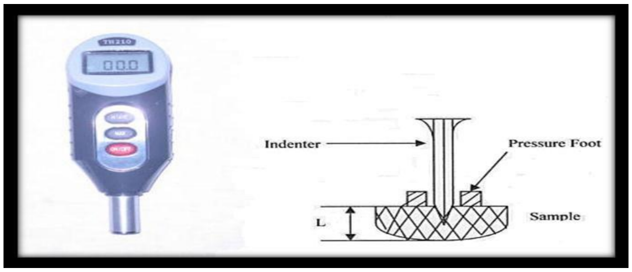


Figure 3: Shore D Hardness Tester.

2.7 Tensile Test Instrument

To determine the mechanical properties of the prepared polymers, standard samples were tested using a tensile test at laboratory temperature. An INSTRON-1122 with a load range of 5 kN was used, equipped with a digital display to record the load, as shown in Figure A. The tensile speed of the testing instrument was set at 0.5 mm/min, and the spacing between the two supports was determined according to the American Standard for Testing of Materials (ASTM-D790) for polyethylene samples. The tension was applied to both ends of the sample.

We immersed several tensile samples in dilute sulfuric acid and repeated the test at intervals of 5–1 weeks. The results were then plotted graphically, as will be explained later.

Figure 4: Tension testing device

Tensile specimens are prepared with specific dimensions, and the cross-section of the test specimen is strip-shaped. The specimen is secured in the apparatus using special holders after its dimensions have been calculated. The tensile axis must be aligned with the axis of the test piece. Ripped ends may be flat, pointed, or screwed to fit the test machine's holders [Gültekin, 2022]. A gradually increasing load is applied to the specimen (a suitable and constant pulling force) until the specimen fails. The maximum force required to break the specimen and the maximum elongation before breaking are recorded. The tensile strength (σ) is determined by dividing the maximum load the material can withstand (F) by the original cross-sectional area (A), as shown in the equation below. [Nikam, 2023]

$\sigma = F/A$........................

3. Results and discussion:

3.1 Impact Test Results

Impact testing is an important dynamic mechanical test in which a material is subjected to a very rapid kinetic load. Impact testing of polymer composite material samples was performed using the Charpy Test. The principle of this test is based on the fact that some of the initial energy contained in the hammer, such as potential energy, is absorbed by the sample before fracture occurs. (The energy absorbed by the sample depends on the nature of the components used in the composite material's manufacture and its resistance to external stress.) Our goal is to measure the resistance to crack growth in the composite material, which depends on its ability to absorb the energy present at the crack. [Palza, 2016]

The results showed that the best performance in pre-immersion impact energy absorption values was achieved at 1% silica due to enhanced toughness without particle agglomeration. The addition of nano-silica also improved impact resistance, with the decrease after immersion being less with an increasing reinforcement ratio.

However, after immersion in sulfuric acid (0.2%), we found that immersion reduced impact energy due to the deterioration of the polymer structure and the formation of microcracks. We found that unreinforced samples were significantly more affected and decreased upon immersion compared to reinforced polyethylene. The presence of silica particles improves impact resistance, but only to a certain extent (better at 1%). Higher ratios sometimes lead to agglomeration and impaired performance. The results were as follows.

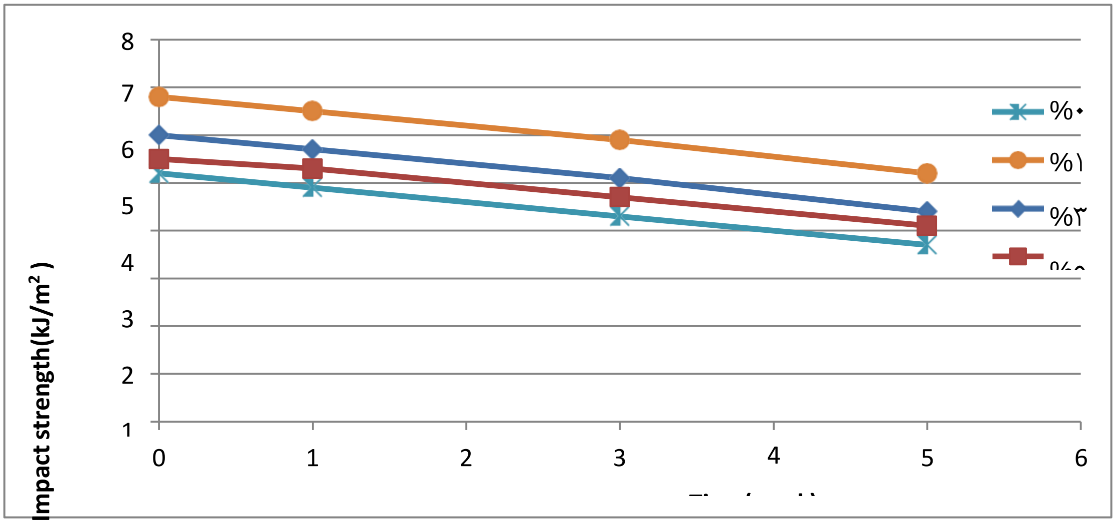


Figure 5: Change in shock resistance values before and after immersion in the acid solution.

3.2 Hardness Test Results

Before immersion, hardness values increased with increasing nano-silica content, indicating enhanced material resistance.

After immersion, we found that the effect of dilute sulfuric acid (0.2%) on the hardness of reinforced and unreinforced polyethylene depended on time and the interaction between the material and the acidic medium. Generally, polyethylene is relatively resistant to chemicals, but over time, surface changes and mechanical structure deterioration may occur, especially in unreinforced materials. Reinforced samples maintain a significant percentage of their hardness due to the protection provided by the nano-silica particles. This contributes to improving the chemical stability of reinforced polyethylene with 1%, 3%, and 5% silica particles. The results were as follows:

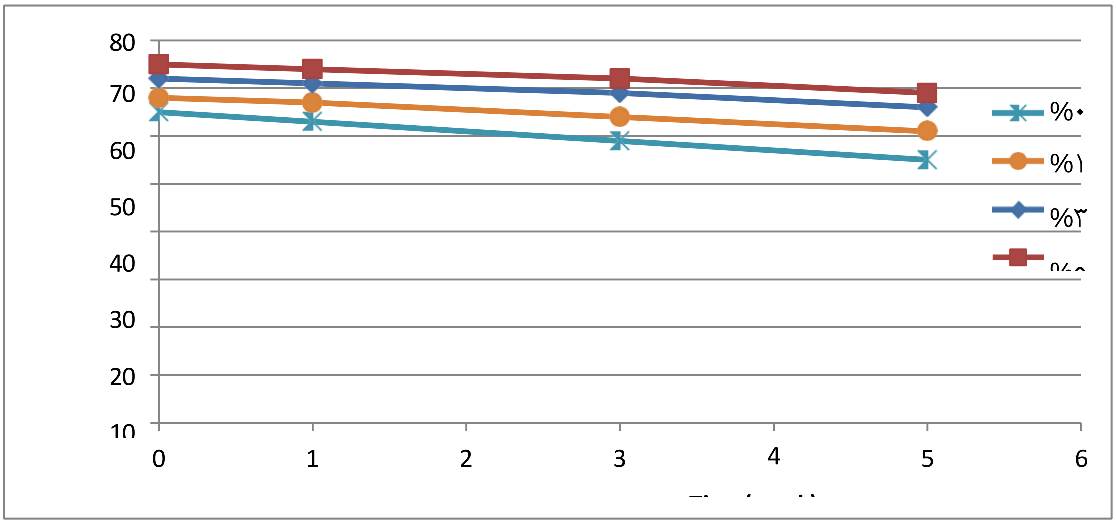


Figure 6: Change in hardness values before and after immersion in the acid solution Tensile

3.3 Tensile Test

Reinforced samples retained their mechanical properties better than unreinforced samples. Unreinforced polyethylene is more susceptible to chemical damage from acid, albeit at a lower rate.

Silica nanoparticles improve the material's resistance to chemical corrosion to some extent, but their effect diminishes over time. We note that by the fifth week, the cumulative effects of acid begin to weaken the mechanical structure, even in reinforced materials.

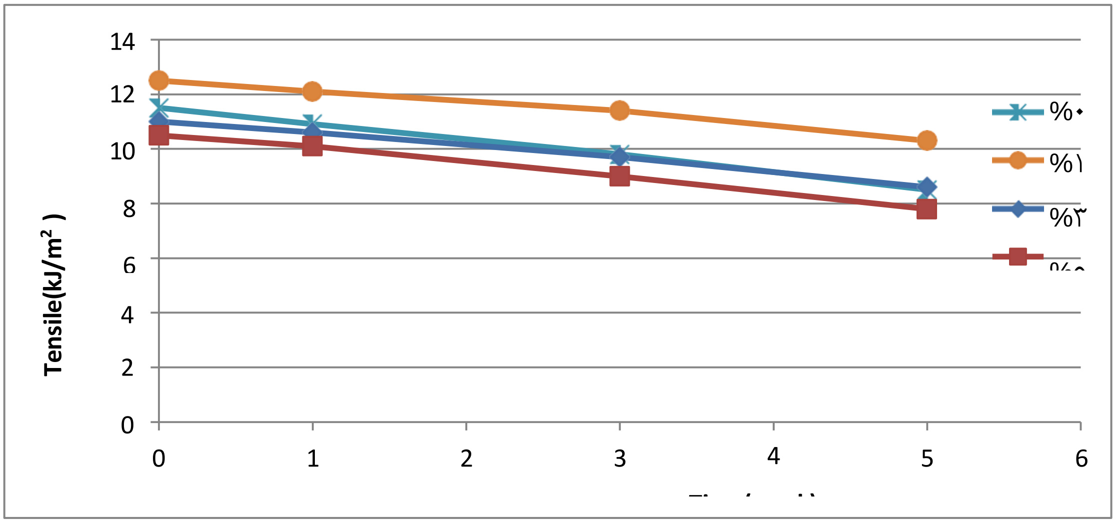


Figure 7: Change in tensile values before and after immersion in the acid solution tensile

4. Conclusions

The conclusion highlights that reinforcing polyethylene with silica nanoparticles notably enhances its mechanical properties, including tensile strength and impact resistance, particularly at moderate volume fractions like 0.1–0.3. The addition of silica also improves the material's resistance to chemical corrosion, especially when exposed to dilute acids. Moreover, while mechanical performance naturally declines after prolonged immersion, the reinforced composites retain their properties better than unreinforced polyethylene. Finally, by choosing the appropriate volume fraction of silica (such as 0.1), it is possible to achieve a desirable balance between easy processing and high performance in the resulting composite material.

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