Study of Enhancement of Mechanical Performance of Polymers via Particle Reinforcement Offered as an Independent Study Course

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Abstract

Engineering courses offered as independent study classes help students to understand real-life problems and promote the use of theoretical knowledge gathered in other engineering classes for practical applications. We have created multiple independent study classes for students in the areas of applied research with broad potential applications. By working in a laboratory environment, students are exposed to diverse equipment and materials. Independent study courses help students to plan their research, perform measurements, collect data and analyze the results. They are working together as a team towards meeting the deadlines and for preparing and presenting their results in conferences. In the current research, students are studying polymer-based composites, an important class of materials that are used in many fields including aerospace, and automotive applications. Epoxies are a major group of lightweight polymers that are commonly used as the matrix of composites. Recently, there has been a constant interest in improving their strength and wear resistance. This independent study is introducing students to epoxy-based composites and aims to evaluate the effects of the addition of glass beads (micro-scale particles) and alumina powder (nano-scale particles) on the mechanical and abrasive properties of the epoxy-based composites. Epoxy samples were manufactured in the lab with different percentages of particles (0, 5, 10, 15 weight percentage) and the mechanical properties of fabricated composites were evaluated by students using the existing equipment (i.e. flexural strength, elastic modulus, wear/ abrasive resistance). A few specimens were exposed to accelerated weathering conditions including UV radiation, high temperature, and moisture by using an environmental chamber and the influence of the filler particles on the mechanical performance was monitored.

Keywords

Particle reinforcement; Epoxy-based nanocomposites; Glass beads fillers; Alumina oxide nanoparticles; Abrasion testing; Flexural testing.

Introduction

During the independent study classes, students have the opportunity to apply theoretical knowledge to real-life situations and find solutions to problems while working with multiple equipment and materials. Students are initially performing a literature search to find the most recent published research in the area and to understand the relevance of their work. For this particular class, they need to find ways to manufacture the epoxy-based composites and define the standardized procedures for testing and reporting their properties. Upon successful completion of the independent study course, students are able to methodically search current literature and select pertinent information that relates to the experimental topic. They are becoming knowledgeable of polymers and composites properties and manufacturing methods. Also, they are becoming familiar with using standardized procedures and multiple laboratory equipment (accelerated weathering testing machine and three-point bending, tensile, and abrasion testing equipment). Students are also able to gather data in an organized manner to create posters and present their findings in conferences. The independent study class was designed to address ABET Outcome 5 requirement for students to build the ability to function effectively on a team to "establish goals, plan tasks, meet deadlines", and create a collaborative environment. It also addresses ABET Outcome 6 requirement for students to "develop and conduct appropriate experimentation, analyze and interpret data".

Epoxy resins are widely used polymers due to their relatively low manufacturing cost, high chemical and heat resistance, and good mechanical properties. For most applications epoxies are subjected to harsh environmental conditions such as moisture, UV radiations, and extreme temperatures. During their service, they will also be subjected to wear (abrasive, adhesive, and fatigue) with detrimental effects on their durability and lifetime[1, 2]. In order to enhance the epoxy performance, different types of fillers are used to create the composites, such as titanium oxide, aluminum oxide in the form of micro and nanoparticles, silica nanoparticles, glass fibers, or glass beads[3-6]. Epoxy-based composites are recognized for their high strength, stiffness, and corrosion resistance, while remaining lightweight[7-9]. The present study requires students to plan and perform research on enhancing the mechanical performance of epoxy-based composite materials by using nanometer size alumina particles and micrometer size glass beads as fillers. Alumina powder (50 nm particle size) and glass beads (9-13 micrometer particle size) were added to the epoxy matrix with different weight percentages. Students developed a procedure to create samples with a uniform dispersion of particles. A few specimens were subjected to 400 hours of standardized sequential exposure to UV radiation, high temperature, and moisture using a Q-UV environmental weathering chamber (according to the ATSM G154 standard). Students planned the experiment by setting the exposure times according to the standard and monitoring and maintaining the weathering chamber functionality. Flexural properties are examined by using a three-point bending test, using a Mark-10 ESM303 equipment (according to the ASTM D790 standard). Abrasion tests were performed using a Taber Industries 5900 Reciprocating Abraser (following the GMW14125 testing standard). The research team performed all the testing procedures, as well as collecting and analyzing the results of the tests.

Experimental Methods

Samples Preparation

Multiple samples were manufactured by students for this research (at least three for each testing condition) consisting of epoxy matrix with glass bead microparticles or alumina nanoparticles reinforcement at 5, 10, and 15 weight percentages. The epoxy matrix consisted of 635 Epoxy Resin, from U.S. Composites Inc, the alumina powder used as reinforcement was LECO Gamma alumina powder agglomerate-free with 0.05 μm size, and the glass bead microparticles used were Aldrich Chemistry 440345 glass spheres with a size range of 9-13 μm. Students selected and ordered the materials. In order to create the samples, the epoxy resin was initially heated to 80°C and the appropriate amount of alumina powder nanoparticles or glass beads microparticles were added to achieve the desired weight percentage for each composition. The mixture was hand-mixed for 20 minutes and later was placed into a LECO UC-100 Ultrasonic Equipment for 30 minutes and continuously mixed to ensure a uniform distribution of the added particles in the mixture. For the next stage of the sample preparation, the epoxy hardener was added to the mixture with a ratio of 1:4, it was carefully hand-mixed and was later injected into the 75-80 RTV liquid urethane mold and allowed to solidify. The mold was previously manufactured to create samples with dimensions of 127 × 12.7 × 3.2 mm following the ASTM D790 standard. Aluminum samples with the standardized dimensions were used to create the cavities in the mold and the molding rubber was poured over the aluminum samples in a pan and allowed to cure for 24 hours at room temperature. The rubber was later removed from the pan and the aluminum samples were removed from the cavities. The epoxy hardener was added to the composite resin with a volume ratio of 1:4 to speed the curing time of the resin. The final mixture was injected into the rubber mold and allowed to solidify. Figure 1 is a schematic view showing the sequential stages of the specimens manufacturing. The process was optimized by continuous discussions and collaboration between team members and under the instructor's guidance.

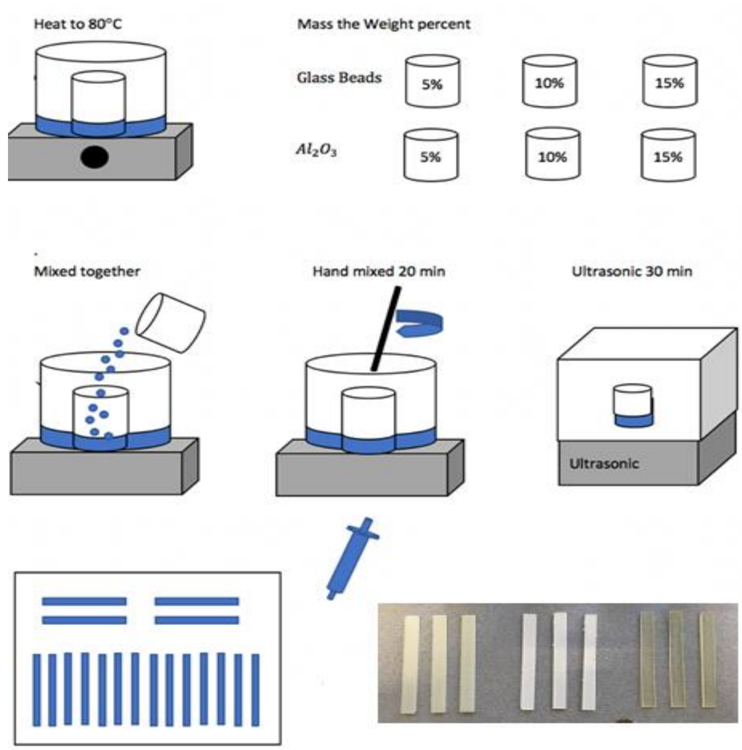

Figure 1. Schematic view of the epoxy-based composites samples preparation

Environmental Exposure

After the curing process of samples was finalized, a few composite samples were selected and exposed to standardized cycles of UV radiation, moisture, and high temperature to explore the effects of the harsh environmental exposure on the composites. The samples were sequentially exposed to 8 hours of UV radiation followed by 4 hours of condensation in a Q-UV environmental weathering chamber according to the ASTM G154 standard for 400 hours. Students selected the exposure sequence in accordance with the standards, maintained the functionality and monitored the performance of the weathering chamber.

Mechanical Testing

Flexural and abrasion mechanical testing was performed on the samples to determine the effects of the particle reinforcement addition to the epoxy matrix. Both unexposed and exposed samples were tested for their flexural and abrasion performance. The flexural test (three-point bending) was performed according to ASTM D790 standard using a Mark-10 ESM303 equipment. The displacement rate and support span used for this test were 1.4 mm/s and 51.2 mm respectively as recommended by the standard. The abrasion testing was performed using the Taber Industries 5900 reciprocating wear equipment. Samples were tested using two standardized grade tips: H-18 and H-22 in order to observe the influence of using different abraders with different roughness. The abrasion test was done using a reciprocated cycle length of 60 mm, performing 3600 cycles at a rate of 60 cycles per minute. This resulted in a test that lasted approximately one hour with a total travel distance of 216 meters on each sample. Students developed multiple testing procedures before determining the best testing conditions that can offer reliable results. The mass of the sample was measured before and after performing the abrasion test to determine the weight by using a Cole-Parmer Symmetry PA 124E analytical balance and the mass loss for each sample was recorded. Additionally, the depth of the wear track was examined using a KLA Tencor D-500 profiler. A minimum of three samples were tested for each condition.

Results and Discussion

Flexural Test

The flexural properties of the epoxy and epoxy-based composites were evaluated according to the ASTM D790 standard and results were collected and analyzed by students under the direction of instructors. For example, the average flexural strength of the regular epoxy was 54.8 MPa and it was observed that for both filler materials, an increase in the filler weight percentage resulted in a decrease in the flexural strength. The glass bead epoxy-based composites displayed a higher flexural strength than the alumina reinforced samples. For example, the 15 wt. % alumina/epoxy composite displayed an average flexural strength of 21.5 MPa while the 15 wt. % glass beads/epoxy composite displayed a flexural strength of 43.6 MPa. Lower values of the flexural strength were expected for composites compared to pure epoxy since adding the filler material could create bonding related problems that could act as crack initiators. The failure strain and flexural toughness showed similar trends with the flexural strength, while the flexural modulus remained relatively unchanged for all samples. The average flexural modulus of the regular epoxy was 2.38 GPa, which did not show significant change with the increase in filler material. Figure 2 shows the stress-strain response for epoxy and alumina nanoparticles reinforced epoxy. The glass beads microparticle reinforcement had similar trends.

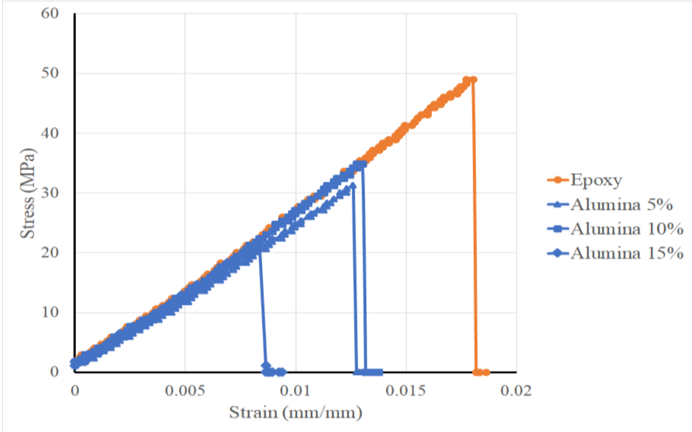

Figure 2. The stress vs. strain curves for pristine epoxy and 5, 10, and 15 wt. % alumina nanoparticles reinforced epoxy matrix

Figure 3 is representing the change in (A) flexural strength, (B) failure strain, (C) flexural modulus, and (D) flexural toughness with increasing the weight percent of alumina nanoparticles and glass beads microparticles additions to the epoxy.

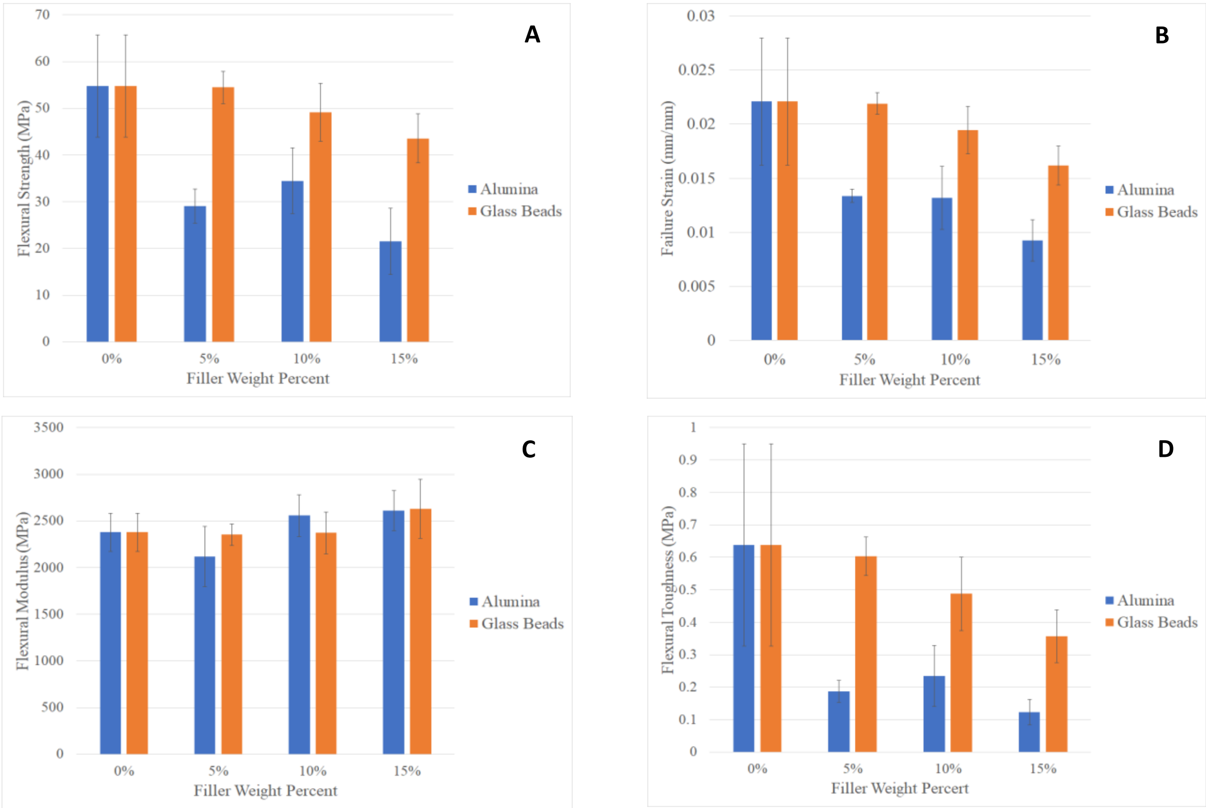

Figure 3. Flexural testing results: (A) flexural strength; (B) failure strain; (C) flexural modulus, and (D) flexural toughness for alumina nanoparticles and glass beads microparticles additions to the epoxy

Abrasion Test

Two different abrasive tips were used for performing the abrasion testing: H-18 and H-22 (Taber Industries) in order to observe the influence of the abrader roughness on the composite wear resistance. A comparative view of each of the tips is displayed in Figure 4 where it is observed that the H-22 tip is sharper and more aggressive, therefore likely to remove more material.

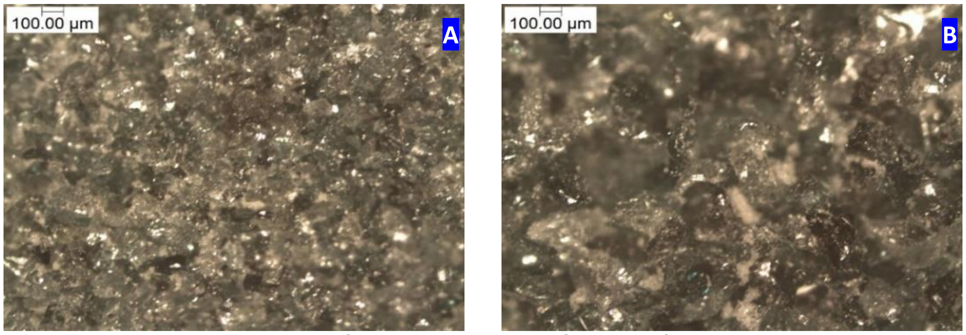

Figure 4. Optical microscopy of abrasive tips before performing the abrasive test (50X magnification): H-18 (A); H-22 (B)

The results of performing the abrasion tests for one hour for each test are evaluated by weight loss measurements, using the analytical balance. Figure 5 is representing the mass loss results for pristine epoxy with different percentages: 0, 5, 10, and 15 wt. % of alumina nanoparticles and glass beads microparticles addition, tested with H-18 and H-22 ceramic abrasive tips. It was observed that the abrasion resistance was not improved by using the glass beads addition. Glass beads particles were larger (micrometer scale), therefore they bonded weaker with the epoxy matrix and were easier to dislodge, leading to significant mass loss during the abrasion testing. However, with the alumina nanoparticles addition, the abrasion behavior improved due to the smaller size of the particles that ensured a better bonding to the epoxy matrix and due to the higher hardness of the alumina nanoparticles embedded in the epoxy matrix.

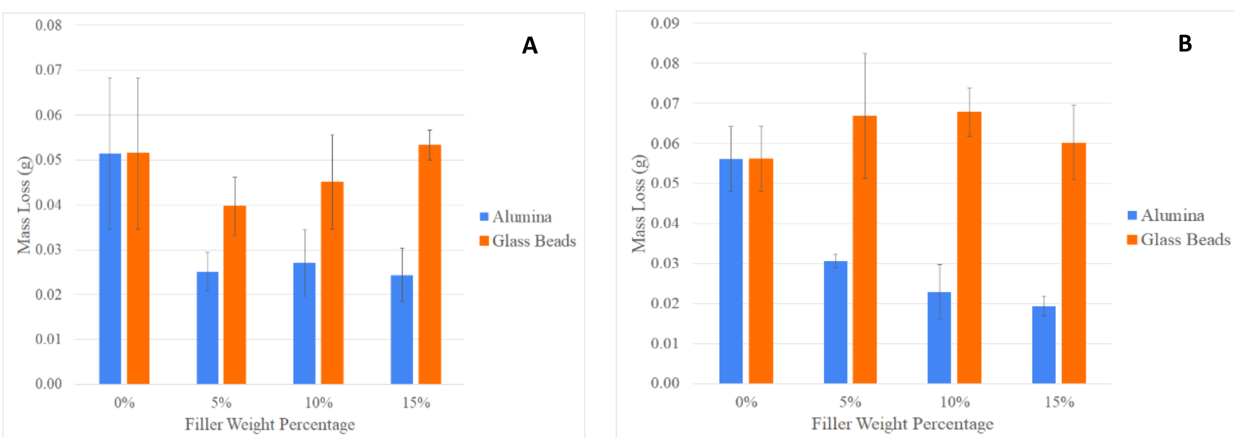

Figure 5. Mass loss of pristine epoxy and composites tested with (A) H-18 and (B) H-22 abrasive tips

The preliminary results of samples tested for abrasion after 400 hours of exposure to harsh environmental conditions showed improvement behavior for composites compared to pristine epoxy. The research was planned by students and guided by professors during this independent study class. Students used notebooks to record their measurement results. They also recorded the daily work progress, plans, observations made during experiments, and comments on the results. Students also had biweekly homework assignments for literature search presentations and search related to equipment used for the project. They had three presentations during the semester including the literature search, equipment description, and presentation of results and discussions counting as part of their grades. The project finalization required a presentation similar to a conference presentation and a poster covering all stages of the project.

Conclusions

An independent study class was created in order to offer students the possibility to perform research in the advanced materials field and apply the theoretical knowledge for finding solutions towards materials behavior improvement. Students worked in teams in order to perform this research and to find optimized solutions for manufacturing composites. The purpose of creating epoxy-based composite materials was to improve their abrasion resistance and their resistance to harsh environmental conditions. Students learned how to use the research related equipment, and planned all experiments under the instructor's guidance. They also performed the periodic maintenance to the research-related equipment. They observed that flexural and abrasion behavior are altered by the introduction of glass beads and alumina particles as filler materials. The filler material hardness and particles size are influencing the properties of the resulting composite. The flexural response decreased with increased percentages of filler material; however, the abrasion resistance was enhanced with higher percentages of filler particles. The alumina nanoparticle epoxy-based composite displayed enhanced abrasion resistance and good response to harsh environmental conditions. Students collected and analyzed the results, prepared presentations and posters to share their findings to technical conferences.

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