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Experimental Investigation of Mechanical Properties of Fly Ash Filled E-Glass Fiber Reinforced Polyester Composites

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Abstract — Fly ash filled polymer composites offer a route for combining the structural contribution of E-glass fiber with particulate reinforcement derived from an industrial residue. This work experimentally compares three polyester-based formulations: S1, neat polyester resin; S2, 60 wt.% polyester resin with 40 wt.% E-glass fiber; and S3, 40 wt.% polyester resin, 40 wt.% E-glass fiber and 20 wt.% fly ash. Composite laminates were produced by hand lay-up and cured under room-temperature conditions. The project specimens were subsequently evaluated using pendulum impact testing and Rockwell hardness testing. The reported impact-energy values were 0.611, 0.738 and 0.865 N-m/mm² for S1, S2 and S3, respectively. Relative to S1, S2 and S3 showed increases of approximately 20.8% and 41.6%, respectively. The source report also records Rockwell hardness values of 97, 75.3 and 275 for S1–S3; however, the S3 value and the associated hardness discussion are internally inconsistent and should be rechecked against the original laboratory record before publication. The impact results nevertheless indicate that the hybrid E-glass/fly-ash formulation provided the highest reported impact-energy response among the investigated compositions.

Keywords— fly ash; E-glass fiber; polyester resin; hybrid composite; hand lay-up; impact energy; Rockwell hardness.

I. INTRODUCTION

Polymer matrix composites are engineered by combining a continuous matrix with one or more reinforcing phases. The matrix transfers load, protects reinforcement and provides the geometry of the component, while fibers and particulate phases can alter stiffness, strength, fracture response and other functional properties. The submitted project report focuses on an E-glass reinforced polyester system modified with fly ash, with emphasis on hardness and impact response. The study is motivated by the potential to use an industrial particulate residue as a filler while retaining the reinforcement contribution of glass fiber.

Previous work cited in the project report has considered waste-glass particles, glass-powder-filled polymers, glass/epoxy systems, hybrid fiber composites and fly-ash-containing materials. The literature summarized in the project indicates that filler fraction, particle size, fiber content and matrix–reinforcement interaction can substantially influence composite behavior. Particulate additions can also change energy absorption and stiffness, although the direction and magnitude of the effect depend on dispersion, interface quality and processing.

The objective of the present paper is to condense the original B.Tech experimental investigation into a journal-style manuscript and to compare the mechanical response of the three reported compositions. The specific objectives are to: (1) fabricate polyester/E-glass/fly-ash laminates using hand lay-up; (2) compare the reported impact-energy response of neat resin, E-glass/polyester and E-glass/polyester/fly-ash specimens; and (3) document the reported hardness results while explicitly identifying data that require verification.

II. MATERIALS AND EXPERIMENTAL METHOD

1. Materials

The materials documented in the project are woven E-glass roving mat, unsaturated polyester resin, fly ash, methyl ethyl ketone peroxide (MEKP) and cobalt. The report describes polyester as the thermosetting matrix and identifies MEKP and cobalt as components of the curing system. The fly ash used in the experimental work was physically collected and incorporated into the hybrid formulation. No particle-size distribution, chemical composition or morphology characterization of the fly ash is reported in the project.

2. Composite Formulations

Table 1. Nominal Material Compositions Reported In The Project

Specimen	Polyester (wt.%)	E-glass (wt.%)	Fly ash (wt.%)	Description
S1	100	0	0	Neat polyester reference
S2	60	40	0	E-glass/polyester
S3	40	40	20	E-glass/polyester/fly ash hybrid

3. Fabrication by Hand Lay-Up

A wooden/plywood open mould was prepared and a release layer/grease was applied. The E-glass fabric was cut to the required dimensions. Polyester resin was mixed with MEKP and cobalt according to the project procedure. Resin was distributed in the mould, followed by placement of the E-glass reinforcement and additional resin wet-out. For S3, fly ash was included in the specified 20 wt.% formulation. A roller/brush was used to spread the resin and consolidate the laminate. The fabricated plates were allowed to harden under ambient conditions, removed from the mould and finished using emery paper before specimen cutting.

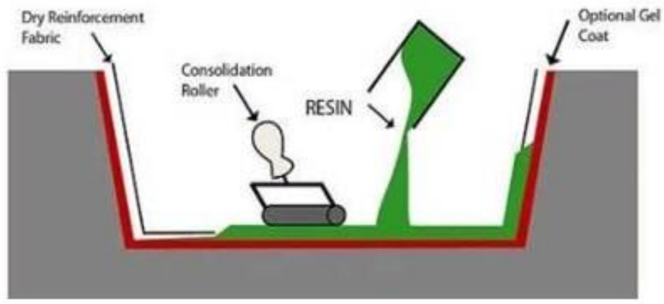

Fig. 1. Hand lay-up process illustrated in the submitted project report.

4. Impact Test

The project identifies ASTM D256 as the basis for pendulum impact testing. The specimens were machined to the reported geometry: 55 mm overall length, 10 mm width, 10 mm depth and a central 45° notch with a reported 2 mm notch dimension. The specimen was clamped with the notched side facing the striking edge and the pendulum was released to fracture the specimen.

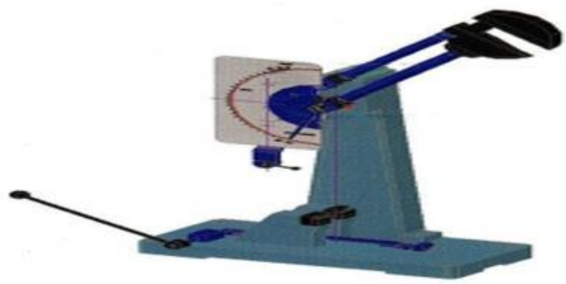

Fig. 2. Impact-testing machine used in the experimental work.

ASTM D256 specifies standardized pendulum impact methods and emphasizes that specimen preparation, dimensions, notching, mounting and conditioning influence the measured energy. cite turn0search0 turn0search4 The present manuscript therefore treats the reported impact values as a within-study comparison rather than as universally transferable material properties.

5. Hardness Test

Hardness was measured using a Rockwell-type machine. The project records a 100 kg load and B-scale indentation for all three specimens, with three trial readings used to report a Rockwell hardness number. The source report gives trial readings of 29, 32 and 36 for S1; 72, 78 and 76 for S2; and 99.5, 85 and 87.5 for S3, followed by reported hardness numbers of 97, 75.3 and 275, respectively.

III. RESULTS AND DISCUSSION

1. Impact-Energy Results

Table 2. Reported Impact-Test Observations

Specimen	Hammer before (N-m)	Hammer after (N-m)	Absorbed (N-m)	Reported impact energy
S1	168	120	48	0.611 N-m/mm²
S2	168	110	58	0.738 N-m/mm²
S3	168	100	68	0.865 N-m/mm²

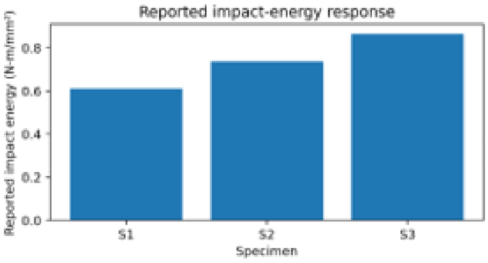

Fig. 3. Reported impact-energy comparison of the three formulations.

The absorbed hammer energy increased from 48 N-m for S1 to 58 N-m for S2 and 68 N-m for S3. Using the reported normalized values, the increase from S1 to S2 is approximately 20.8%, while the increase from S1 to S3 is approximately 41.6%. The highest reported impact-energy value therefore occurs for S3, the composition containing both 40 wt.% E-glass fiber and 20 wt.% fly ash.

The observed trend is consistent with the qualitative interpretation in the project report that the hybrid formulation exhibited the highest impact and hardness response. A plausible materials interpretation is that the combined reinforcement phases alter crack initiation and propagation and increase the amount of energy dissipated before complete fracture. However, the present dataset does not include replicate measurements, standard deviations, fracture-surface microscopy or quantitative characterization of filler dispersion. Consequently, the mechanism should be regarded as an interpretation rather than a directly verified causal explanation.

2. Hardness Results

Table 3. Reported Hardness Observations

Specimen	Trial 1	Trial 2	Trial 3	Reported Rockwell number
S1	29	32	36	97
S2	72	78	76	75.3
S3	99.5	85	87.5	275

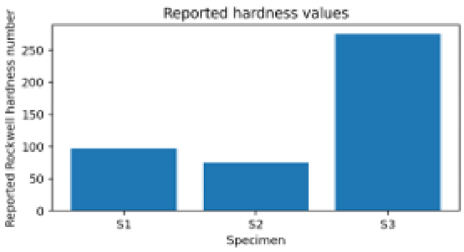

Fig. 4. Reported hardness values; S3 requires verification before quantitative publication.

The hardness dataset requires particular caution. The source report gives three trial indentation-related readings for each specimen but then reports hardness numbers that do not consistently follow from those readings. The reported S3 value of 275 on the B scale is especially problematic because it is outside the normal numerical range associated with Rockwell B reporting. Furthermore, the project conclusion contains separate hardness values in MPa that do not correspond directly to the Rockwell table. These discrepancies cannot be resolved from the available report without access to the original instrument records. For scientific integrity, the present manuscript does not replace the source values with estimated values.

3. Comparative Interpretation

Considering the reliable portion of the dataset, the hybrid S3 formulation is the most promising composition for impact-energy absorption among the three tested materials. The change from S2 to S3 is notable because both contain the same nominal 40 wt.% E-glass fraction, while S3 replaces 20 wt.% of the polyester fraction with fly ash. The reported impact-energy increase from 0.738 to 0.865 N-m/mm² corresponds to approximately 17.2% improvement relative to S2.

This result suggests that fly ash did not reduce the impact-energy response under the specific fabrication and testing conditions used in the project. Nevertheless, the study does not establish an optimum fly-ash concentration because only one fly-ash level, 20 wt.%, was evaluated. A broader composition matrix would be required to identify a maximum and to distinguish a true material trend from specimen-to-specimen variability.

4. Reproducibility and Data Quality

Several experimental details required for a journal-quality reproducibility assessment are not fully documented in the project report. These include the exact resin-to-MEKP/cobalt ratio used for every batch, fly-ash particle size and pre-treatment, laminate thickness, fiber areal density, number of plies, void content, conditioning time and temperature, number of replicate impact specimens, and the calibration status of the hardness machine. These omissions do not invalidate the reported observations, but they limit the strength of generalization. Elsevier's author guidance likewise emphasizes that an experimental article should provide sufficient detail for an independent researcher to reproduce the work. cite turn0search1 turn0search12

IV. CONCLUSIONS

- The three reported formulations—neat polyester (S1), 60 wt.% polyester/40 wt.% E-glass (S2), and 40 wt.% polyester/40 wt.% E-glass/20 wt.% fly ash (S3)—were fabricated by hand lay-up.
- The reported impact-energy values were 0.611, 0.738 and 0.865 N-m/mm² for S1, S2 and S3, respectively.
- S2 exhibited approximately 20.8% higher reported impact energy than S1, while S3 exhibited approximately 41.6% higher impact energy than S1.
- Relative to S2, the hybrid S3 formulation showed approximately 17.2% higher reported impact energy, indicating the highest impact-energy response within the tested set.
- The hardness table in the source report contains internally inconsistent values and should be re-tested or verified from the original machine records before peer-reviewed publication.
- The study supports further investigation of fly ash as a particulate phase in E-glass/polyester composites, but the optimum filler level cannot be established from the three-composition dataset.

Limitations and Future Work

Future experiments should use at least three independently fabricated specimens per composition and report mean ± standard deviation. A systematic fly-ash study should evaluate several filler fractions, for example 0–30 wt.%, while maintaining a controlled fiber fraction. Fly-ash particle-size distribution, morphology and chemical composition should be characterized, and the dispersion of particles within the resin should be examined using optical microscopy or scanning electron microscopy. Mechanical characterization should be expanded to tensile, flexural, compression, interlaminar and wear properties, together with density and water absorption. Fractography would help establish whether the observed impact response is governed by crack deflection, fiber pull-out, particle debonding or other mechanisms.

Acknowledgment

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Publication Readiness Statement

This manuscript has been condensed and rewritten from the submitted B.Tech project report while retaining its reported compositions, test procedures and numerical results. No unreported experimental values have been fabricated. Where the source report contains inconsistent hardness values, the inconsistency is explicitly identified rather than silently corrected. This approach is important for responsible publication because a peer-reviewed article should distinguish measured data from interpretation and should make unresolved data-quality issues visible to the reader.

Recommended Characterization Matrix

A useful next-stage design would retain the 40 wt.% E-glass fraction and vary fly-ash content across several levels, including a zero-filler control. Tensile and flexural tests would quantify load-bearing behavior, while impact testing would provide energy-absorption data. Density and water absorption measurements would establish whether the filler produces a useful property trade-off. Optical or scanning electron microscopy could be used to assess particle dispersion, fiber wet-out and fracture morphology. If sufficient specimens are available, analysis of variance can be used to determine whether observed composition effects are statistically significant.

Experimental Uncertainty and Recommended Validation

The largest limitation is the absence of replicate statistics. A single reported value for each formulation cannot establish repeatability, and differences of a few percent could be caused by specimen-to-specimen variation. Future testing should use multiple independent coupons from more than one laminate plate and report mean, standard deviation and confidence intervals where appropriate. The fabrication record should also specify resin batch, catalyst concentration, mixing time, curing duration, ambient temperature and humidity, fiber areal weight, laminate thickness and final specimen dimensions. These controls would allow the contribution of fly ash to be distinguished from processing variability.

Engineering Significance

From an engineering perspective, the S3 formulation is the most promising of the three investigated compositions when impact-energy absorption is the principal selection criterion. The result is relevant to applications in which moderate-cost polymer composites are required and where incorporation of a particulate residue is desirable. However, impact resistance alone is insufficient for component qualification. A material intended for structural service must also satisfy tensile, flexural, fatigue, environmental and dimensional requirements. Consequently, the present result should be viewed as a screening-level finding that identifies S3 for more detailed characterization.

Interpretation of the Hybrid Effect

The improved impact response of S3 may be associated with the combined presence of E-glass and fly ash, but the available evidence does not permit a unique mechanism to be assigned. In fiber-reinforced polymers, impact fracture may involve matrix cracking, fiber fracture, fiber pull-out, interfacial debonding and crack deflection. A particulate phase can additionally create local stress concentrations or alter crack trajectories. Depending on particle dispersion and interface strength, either strengthening or premature debonding may occur. Since the present study does not include fracture-surface microscopy or controlled particle-size measurements, these mechanisms remain hypotheses for future investigation rather than established findings.

Relative Improvement

The percentage increase in the reported normalized impact-energy value can be calculated directly from the source data.
For S2 relative to S1, (0.738 − 0.611)/0.611 × 100 gives approximately 20.8%. For S3 relative to S1, (0.865 − 0.611)/0.611 × 100 gives approximately 41.6%. For S3 relative to S2, (0.865 − 0.738)/0.738 × 100 gives approximately 17.2%. These calculations are simple comparisons within the same experimental series and do not require assumptions about external datasets.

Expanded Discussion of the Mechanical Response

The impact results provide the most internally coherent quantitative comparison in the source report. S1, which contains only polyester resin, absorbed 48 N-m of hammer energy. The addition of 40 wt.% E-glass in S2 increased absorbed energy to 58 N-m. When 20 wt.% fly ash was incorporated while retaining 40 wt.% E-glass, S3 absorbed 68 N-m. The monotonic sequence S1 < S2 < S3 is therefore evident in both absorbed hammer energy and the normalized impact-energy values reported in the thesis.

Hardness Measurement Considerations

The hardness test was performed after specimens were prepared in circular forms for the hardness machine. The source report describes insertion of the specimen, gradual application of force, a dwell period of approximately 10–15 s, unloading and measurement. Three trial readings were recorded for each material. In a peer-reviewed study, the hardness scale, indenter geometry, minor and major loads, dwell time, specimen thickness and spacing between indents should all be stated clearly. Because the source report labels the test as Rockwell B but provides a value of 275 for S3, this dataset should be rechecked. The manuscript intentionally separates the experimentally reported observation from the conclusion that can safely be drawn from it.

Impact-Energy Calculation

For each impact specimen, the project calculates absorbed energy from the difference between hammer energy before and after striking. The reported values are 168 N-m before striking for all three specimens and 120, 110 and 100 N-m after striking for S1, S2 and S3. Thus, the corresponding absorbed energies are 48, 58 and 68 N-m. The report then normalizes these quantities using the notch-area term and gives 0.611, 0.738 and 0.865 N-m/mm². Because the report does not provide a complete derivation of the normalization term, the present manuscript retains the reported normalized values rather than reconstructing the calculation with assumed geometry.

Laminate Architecture and Specimen Preparation

The conclusion section of the source report describes a three-layer woven-roving laminate and gives a reinforcement orientation notation. The manuscript retains the experimentally relevant description—woven E-glass reinforcement in a polyester matrix—but does not over-interpret the notation because the report does not provide a complete ply-by-ply manufacturing drawing. Specimen preparation is nevertheless important because impact testing is sensitive to dimensions and notch geometry. The source report specifies a 55 mm specimen length, 10 mm width, 10 mm depth and a central 45° notch with a reported 2 mm dimension. The tested specimens shown in the project demonstrate that the fabricated plates were cut into smaller coupons before testing.

Detailed Experimental Considerations

The hand lay-up method used in the project is an open-mould process in which resin is manually distributed over the reinforcement. Its advantages for laboratory-scale work are simplicity, low tooling requirements and the ability to fabricate relatively large plates with basic equipment. The project used a wooden/plywood mould, a roller or brush, beakers and the required resin system. The reinforcement was cut before lay-up, and a release medium was applied to facilitate demoulding. After wet-out and consolidation, the plates were allowed to harden under ambient conditions and were subsequently cut to the required specimen geometries.

Research Gap Addressed by the Present Experiment

A large fraction of the literature summarized in the thesis concerns glass particles, glass/epoxy composites, natural-fiber hybrids or fly-ash-containing systems in matrices other than the exact formulation used here. The present experiment contributes a direct comparison among neat polyester, E-glass/polyester and E-glass/polyester/fly-ash compositions fabricated with the same general hand lay-up route. The study is therefore best regarded as an exploratory experimental comparison rather than a complete optimization study. Its main contribution is the reported impact-energy ranking of the three compositions and the identification of data-quality issues that should be resolved before a larger experimental program is undertaken.

Relevance of Fly Ash as a Composite Filler

The original report cites work on fly ash and other industrial or agricultural residues in polymer and cementitious composites. The common research motivation is the conversion of a low-value residue into a useful engineering constituent. In a polymer matrix, fly ash can act as a rigid particulate phase, but its effectiveness depends on particle characteristics and interface quality. The present project did not characterize particle size, chemical composition or surface treatment; therefore, the manuscript does not attribute the measured improvement to a specific fly-ash chemistry. Instead, the experimentally observed increase in reported impact energy is presented as a formulation-level result that motivates more controlled follow-up work.

Influence of Fiber and Particulate Reinforcement

The project literature also emphasizes that the response of a composite depends on the type, amount and distribution of reinforcement. Fiber reinforcement is normally used to carry a substantial portion of the applied load, whereas particulate fillers can modify local stress transfer and deformation mechanisms. In a hybrid system, the final response is consequently not determined by fiber content alone. Matrix continuity, fiber wet-out, interfacial adhesion, particle dispersion and the presence of voids can all influence fracture and hardness measurements. The present study is particularly relevant because S2 and S3 maintain the same nominal E-glass fraction while S3 introduces fly ash in place of part of the resin fraction. This comparison isolates, at least at the formulation level, the effect of adding a particulate phase to the glass-fiber/polyester system.

Literature Context and Research Positioning

The literature collected in the original project report provides a useful basis for positioning the present experiment. Taurino et al. investigated composites based on glass waste and reported that the addition of waste-glass fillers can modify stiffness and flexural behavior, illustrating the broader feasibility of converting glass-derived residues into composite constituents. Other studies cited by the project examined waste-glass-filled polyester and glass-powder-filled polymer systems, where filler addition was considered both from a mechanical-performance perspective and from a materials-reuse perspective. These studies support the general premise that a particulate phase can be introduced into a polymer matrix without eliminating the processing advantages of polymer composites.

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