Evaluation of Flexural Properties of Fly Ash Filled Polypropylene Composites

Jitendra Gummadi[1], G.Vijay Kumar[1], Gunti Rajesh[2]

[1] *Department of Mechanical Engineering,* Prasad V. Potluri Siddhartha Institute of Technology, *Kanuru,Vijayawada,Andhra Pradesh, India.*

[2]*Department of Mechanical Engineering, DVR & Dr. H S MIC College of Technology, Kanchikacherla, Andhra Pradesh, India.*

Abstract: In recent time's polymer waste disposal is a challenging task as the quantity of polymer waste is increasing day by day. In this research work particulate composites have been developed from recycled polypropylene filled with fly ash. Fillers are used along with various commodities as well as engineering polymers to improve the properties of polymers. The performance of filled polymers is generally determined on the basis of the interface attraction of filler and polymers. Fillers of widely varying particle size and surface characteristics are responsive to the interfacial interactions with polymers. The present study deals with the effect of particle size and its concentration on the properties of fly ash filled polypropylene composites. Five different particle sizes of fly ash are used for sample preparation. Concentration of fly ash is also varied from 0, 10%, 15%, 20%, 25% by weight in the polypropylene. The composite test specimens are prepared using injection molding machine with hand lay up technique as per ASTM D3641 standards. Bending tests on the specimens are carried out by using tensometer. Flexural strength and modulus are calculated from the obtained load values and the result is analyzed for the prepared samples.

Keywords: Polypropylene, Composite, Fly ash, Flexural properties.

I. Introduction

Particulate composites have received considerable interest in the materials field because of their potential for large gains in mechanical and morphological properties. Thermoplastic polymers and especially polypropylene are produced and used today in vast quantities. However, they are seldom used as pure polymers and are usually combined with mineral fillers like fly ash, graphite etc. Fillers find application in the polymer industry almost exclusively, e.g. to improve mechanical, thermal, electrical properties and dimensional-stability. The low modulus of isotropic polypropylene means that it is unsuitable for many load bearing applications. In order to improve the stiffness of polypropylene, two main routes will be considered here. The first route is to improve stiffness by the introduction of foreign fillers, such as glass fibers, to create polypropylene composite materials. The second route is the exploitation of the inherent molecular strength by uncoiling the molecules and orienting them in the direction of loading, so that the load is transferred by the stiff carbon backbone rather than by weak intermolecular bonds.

Fly ash is finely divided mineral residue resulting from combustion of coal in electric generating plants. Fly ash consist mostly of SiO_2, Al_2O_3, and Fe_2O_3 and are present in inorganic incombustible matter present in coal that has been fused during combustion to glassy amorphous structure . Fly ash used in cement industry could be used as filler in plastic products and depending upon the source of coal, contain elements like carbon, Ti, Mg, etc. So the fly ash has combined properties of spherical particles and that of metals and metal oxides.

Polypropylene (PP) is a thermoplastic polymer used in a wide variety of applications including packaging, textiles (e.g., ropes, thermal underwear and carpets), stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, and polymer banknotes. Most commercial polypropylene is isotactic and has an intermediate level of crystallinity between that of Low-Density PolyEthylene (LDPE) and High-Density PolyEthylene (HDPE). Polypropylene is normally tough and flexible, especially when copolymerized with ethylene. This allows polypropylene to be used as an engineering plastic, competing with materials such as acrylonitrile butadiene styrene. Polypropylene has good resistance to fatigue. The melting of polypropylene occurs as a range, so a melting point is determined by finding the highest temperature of a differential scanning calorimetry chart. Perfectly isotactic Polypropylene has a melting point of 171°C (340°F). In this investigation we studied the effect of fly ash with five varying particle sizes and concentration on flexural properties.

Utilization of fly ash as filler for unsaturated polyester resin was studied by Saroja Devi et al.[1]. Measurement of the specific heat of plastic waste fly ash composite material using differential scanning calorimetry was observed by Fujino and Honda [2]. Structure and strength properties of Polypropylene Polymethyl methacrylate fly ash blends developed by Navin Chand and Vashishtha [3]. Mechanical properties of natural rubber filled with fly ash was prepared and observed by Hundiwale et al.[4]. Effect of fly ash on the mechanical, thermal, dielectric, rheological and rphological properties of filled nylon 6 was studied by Suryasarathi Bose and Mahanwar [5]. Utilization of fly ash as filler for polybutyleneterepthalate-toughened epoxy resin was developed by Ramakrishna et al. [6]. Thermal and Electrical behavior of vinylester resin matrix composites filled with fly ash particles was studied by Dipa Ray et al. [7]. Preparation and dynamic mechanical properties of polyurethane-modified epoxy composites filled with functionalized fly ash particulates was observed by Gaohui Wu et al. [8]. Effect of fly ash content, particle size of fly ash, and type of silane coupling agents on the properties of recycled polyethylene terephthalate / fly ash composites was investigated by Seena Joseph et al.[9]. Correlation of mechanical and structural properties of fly ash filled-isotatic polypropylene composites was studied by Dilip Chandra Deb Nath, Bandyopadhyay [10]. Effect of particle size and concentration of fly ash on properties of polyester thermoplastic elastomer composites was examined by Sreekanth et al. [11]. Mechanical and structural properties of polypropylene composites filled with graphite flakes were studied by Akinci [12]. Mechanical properties of epoxy resin – fly ash composite were developed by Manoj Singla and Vikas Chawla [13]. Polyetheretherketone (PEEK) composites reinforced with fly ash and mica was developed by Rahail Parvaiz.et al.[14]. Furfuryl palmitate coated fly ash used as filler in recycled polypropylene matrix composites was observed by Shubhalakshmi Sengupta et al. [15]. Review of literature survey shows that different type of properties like mechanical, thermal, dielectric, rheological, morphological were studied on the particulate composites made from graphite, silica as a filler and thermoplastic materials like Polyaryletherketone, Polybutadiene, Polybutylene, Polybutylene terephthalate, Polycaprolactone as a matrix medium. How ever there is a limited literature available on the particulate composites especially made from Polypropylene and fly ash. Hence in the present study particulate composites made from polypropylene and fly ash are fabricated and studied for flexural properties and the results are analyzed.

II. Sample Preparation

2.1 Material

Polypropylene granules were purchased from Maram polymers Pvt.Ltd, Vijayawada, Andhra Pradesh, India and the filler fly ash was obtained from Vijayawada Thermal Power Station, Kondapalli, Andhra Pradesh, India were used in the sample preparation.

2.2 Fabrication

The polypropylene granules along with fly ash were melted in the vertical injection molding machine with two heating zones set at 160^0 and 120^0. The weights of fly ash in the composite were 0, 10%, 15%, 20% and 25% of total weight of polypropylene. The samples of fly ash/PP composites with varying particle sizes (53-75µm to 212-300µm) and also varying concentration were prepared by vertical injection machine as shown in Figure 2.1, as per ASTM D 3641Standards. Figure 2.2 shows the plain polypropylene sample and the fly ash filled poly propylene composite sample is shown in Figure 2.3. Sufficient pressure is applied on the sample to eliminate voids in the composite. Samples were air cooled at room temperature.

Figure 2.1: Hand Operated Vertical Injection Machine

Figure 2.2: Plain polypropylene sample

Figure 2.3: Fly ash filled polypropylene composite sample

2.3 Mechanical testing of composites

The fabricated specimens were tested using a 2 ton capacity - Electronic Tensometer, METM 2000 ER-I model, with a cross head speed of 2 mm/min in accordance with standard ASTM D790 under ambient conditions. the schematic representation of load application is as shown in Figure 2.4. Load and elongation values are determined for the all samples. Utilizing the experimental values of load and elongation, flexural strength (f_s), flexural modulus and elongation at break were determined. Reported values are the average of five samples in all measurements. Some of the tested samples are shown below in the following figures from Figure 2.5 to Figure 2.9.

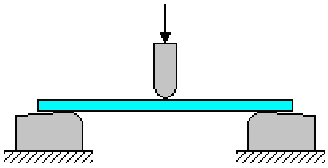

Figure 2.4: Composite specimen flexural test configuration

Figure 2.5: 15 percentage of fly ash at 212-300 microns

Figure 2.6: 20 percentage of fly ash at 76-105 microns

Figure 2.7: 20 percentage of fly ash at 76-105 microns

Figure 2.8: 25 percentage of fly ash at 150-211 microns

Figure 2.9: 25 percentage of fly ash at 76-105 microns

Figure 2.10: 25 percentage of fly ash at 212-300 microns

2.4 Calculation of flexural properties

The flexural stress, flexural strain, flexural modulus and percentage of elongation at break values of the composites were determined by substituting load and elongation values in the below formulae.

Flexural stress $\sigma_f = 3PL/2bd^2$ (for a rectangular cross section)

Flexural strain $\varepsilon_f = 6Dd/L^2$

Flexural modulus $E_f = L^3m/4bd^3$

Following are the notations used in above formulae

σ_f = Stress in outer fibers at mid point, (MPa)

ε_f =Strain in the outer surface, (mm/mm)

E_f =Flexural Modulus of elasticity, (MPa)

P=Load, (N)

L=Support span, (mm)

b=Width of test beam, (mm)

d=Depth of test beam, (mm)

D=Maximum deflection of the center of beam, (mm)

m= The gradient (i.e., slope) of the initial straight-line portion of the load deflection curve,(P/D), (N/mm)

The obtained values are shown below in the Table 1, Table 2 and Table 3.

III. Results And Discussion

From Table 1, it was observed that as the addition of filler decreases the flexural strength. From Figure 3.1, it was observed that rate of flexural strength decrease when large particle sizes were used. This is because of the particle agglomeration at higher filler contents. Particle agglomeration tends to reduce the strength of a material because the agglomerates are weak point in material and break easily when a stress is applied to them. These points then acts as stress concentrator. Agglomerations resulting from larger sized filler particles will produce weaker materials than composites having well dispersion of small sized particles. The rate of decrease of flexural strength is higher in the case of larger particle size of fly ash.

From Figure 3.2, shows the variation of flexural strength with the variation in size of the particles used in polypropylene fly ash filled composites. It was observed that smaller particles showed higher value of flexural strength. For smaller particles, as particle size decreases, interfacial area/unit volume is increased, and hence, flexural strength is increased. The effect of filler on flexural strength may be due to the counterbalance of two phenomenon's with the increase in the filler content in a polymer composite there is increase in effective surface fracture energy, size of voids and agglomeration of filler particles. The dispersed particles make the crack propagation path longer, absorb a portion of energy and enhance the plastic deformation.

Table 1: Flexural Strength of fly ash filled polypropylene composites with fly ash at different sizes and varying percentage content of fly ash

Fly ash sizes → / Percentage of fly ash ↓	53-75µm	76-105µm	106-149µm	150-211µm	212-300µm
0%	56.88	56.88	56.88	56.88	56.88
10%	72.38	59.23	70.71	71.25	73.62
15%	70.29	53.53	59.73	66.18	55.71
20%	66.02	54.44	57.30	61.16	51.36
25%	60.99	57.94	56.80	57.39	44.99

Table 2 shows the values of flexural modulus and from the Figure 3.3, shows the percentage of fly ash at different sizes added to the polypropylene. Figure 3.4, shows the variation of flexural modulus of fly ash composite with filler content and particle size. Flexural modulus increases for smaller filler loading decreases for lager filler loading. Rate of increase is more for smaller particle size than larger ones. Because smaller particles have higher surface area than larger ones, these particles can have higher interaction with matrix at lower concentration of filler. Agglomeration if present, the apparent volume occupied by the filler is increased and agglomeration results in bigger particles by which void space is generated, which can be responsible for strain propagation. The increase in the flexural modulus of PP fly ash composite is due to the increase in the crystalline of composites by addition of fly ash.

Table 2: Flexural Modulus of fly ash filled polypropylene composites with fly ash at different sizes and varying percentage content of fly ash

Fly ash at sizes → / Percentage of fly ash ↓	53-75µm	76-105µm	106-149µm	150-211µm	212-300µm
0%	1591.19	1591.19	1591.19	1591.19	1591.19
10%	1673.33	1506.43	1419.05	1259.15	954.54
15%	2295.47	1940.71	1936.34	1504.68	1276.62
20%	2719.27	2481.59	2390.72	1943.33	1696.05
25%	2565.48	2011.49	1696.05	1329.05	1429.54

Table 3 shows the values of percentage of elongation at break of the composites and from the Figure 3.5, shows the amount of fly ash different sizes added to the polypropylene and the percentage elongation at break is also decreases on addition on filler as shown in Figure 3.6. This is due to the interference of filler in the mobility or deformability of the matrix. This interference is created through the physical interaction and immobilization of the polymer matrix by the presence of mechanical restraints, there by reducing the elongation at break. Fly ash with smaller particle size show higher values of elongation at break when compared to larger particle size.

Table 3: Percentage Elongation at Break for fly ash filled polypropylene composites of fly ash at different sizes and varying percentage content of fly ash

Fly ash at sizes → / Percentage of fly ash ↓	53-75µm	76-105µm	106-149µm	150-211µm	212-300µm
0%	8.91	8.91	8.91	8.91	8.91
10%	7.33	4.43	3.75	3.66	3.46
15%	4.86	3.92	3.66	3.53	3.46
20%	3.97	2.59	2.53	2.29	2.21
25%	2.60	2.56	2.50	2.05	1.97

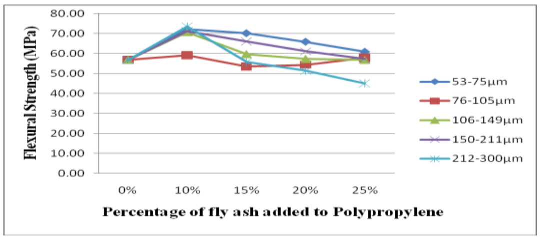

Figure 3.1: Variation of Flexural strength with percentage of fly ash added to the polypropylene Composite

Figure 3.1 shows the flexural strength values of fly ash filled composites at different sizes of fly ash at varying percentages of fly ash. Figure 3.2 shows the flexural strength of fly ash filled composites at smaller particle size and larger particle size i.e.(at 53-75 microns of size and 212-300 microns of size).It was noticed that flexural strength value increases for smaller particle size and the flexural strength value decreases for the larger particle size. This is due to the smaller particle have more surface area when compared to the larger particle.

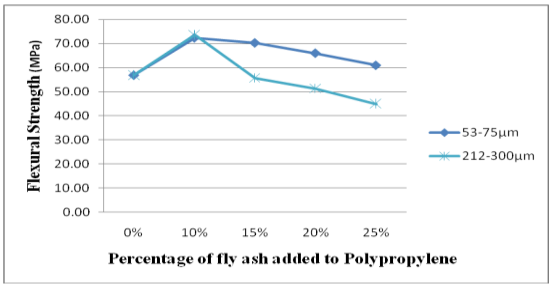

Figure 3.2: Flexural strength variation between the smaller Size particle and the larger Size particle added to polypropylene Composite

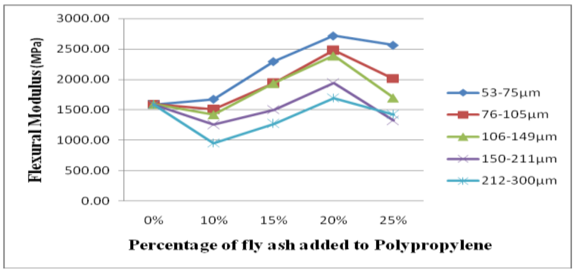

Figure 3.3: Variation of Flexural modulus with percentage of fly ash added to the polypropylene Composite

Figure 3.3 shows the flexural modulus values of fly ash filled composites at different sizes of fly ash at varying percentages of fly ash. Figure 3.4 shows the flexural modulus of fly ash filled composites at smaller particle size and larger particle size i.e. (at 53-75 microns of size and 212-300 microns of size).It was noticed that flexural modulus value increases for smaller particle size and the flexural modulus value decreases for the larger particle size.

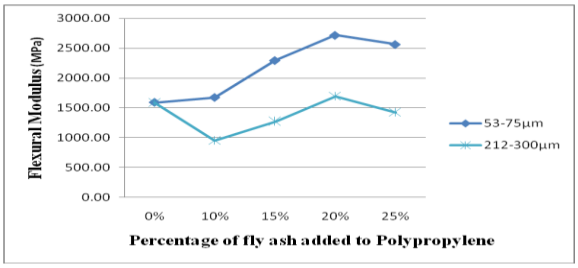

Figure 3.4: Flexural Modulus variation between the smaller Size Particle and the larger Size particle added to polypropylene Composite

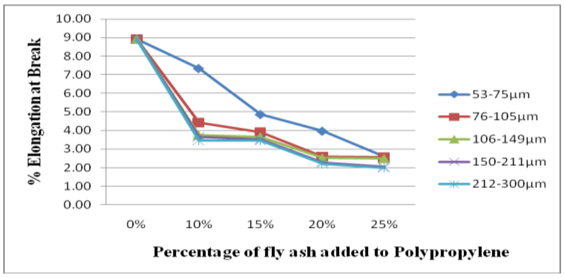

Figure 3.5: Variation of Flexural modulus with percentage of fly ash added to the polypropylene Composite

Figure 3.5 shows the percentage elongation at break values for fly ash filled composites at different sizes with varying percentages of fly ash content with the polypropylene. Figure 3.6 shows the percentage elongation at break of fly ash filled composites for smaller particles and larger particles i.e.(at 53-75 microns of size and 212-300 microns of size). It was noticed that percentage elongation at break value decreases for smaller particle size and the percentage elongation at break value goes on decreasing for the larger particle size.

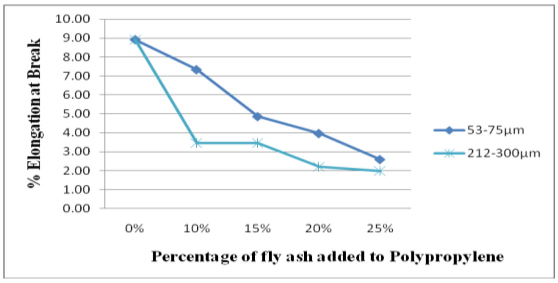

Figure 3.6: Percentage Elongation at Break between the smaller Size particle and the larger Size particle added to polypropylene Composite

IV. CONCLUSION

The flexural properties of fly ash filled polypropylene composites were evaluated in the present research work. Fly ash is found to be good filler for polypropylene matrix composites. With fly ash added to the Polypropylene improves flexural strength and flexural modulus, but dramatically decreases percentage elongation at break. Finest particles showed best flexural strength at all concentrations. The mechanical properties of the composite were found to be a function of the particle size, aspect ratio, the dispersion, the particle orientation, the interfacial interaction between the minerals and the polymer matrix .Spherical shaped filler, such as fly ash gives significant improvement in stiffness due to better surface area for interaction. It is concluded that composites with fly ash at smaller particle size showed significant improvement mechanical properties of composite when compared to the larger particle size of the composites.

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