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Effect of untreated Cenosphere on Mechanical properties of Nylon-6

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Abstract**—** Untreated CS-PA 6 composites were prepared with different loading (10, 20 and 30 % w/w) of CS (5-100 µm) by co-rotating twin screw extruder. Injection molded specimens were prepared to evaluate mechanical properties of developed composites. Mechanical properties like Flexural strength, Flexural modulus, Tensile strength, Impact strength, and Hardness and Abrasion resistance were evaluated for these composites. Addition of Cenosphere improves flexural modulus, flexural strength, and hardness and abrasion resistance besides reducing cost of the final product. As Cenospheres are generated from fly ash in thermal power plant, they are environment friendly, eco-friendly and help to preserve natural virgin filler. The results suggest application of Cenosphere filled Nylon-6 in light weight automotive parts instead of glass filled Nylon-6.

Keywords*- Cenosphere, Nylon-6, Mechanical properties, Flexural strength, Flexural modulus, Tensile strength, Impact strength, Hardness and Abrasion resistance*

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I. INTRODUCTION

A Cenosphere (CS) is a light weight, hard and rigid, waterproof, inert and hollow sphere which can be used as a cost effective filler to improve the properties of Nylon-6 and to produce a new class of engineering composite for automobile application. Cenospheres are 70% lighter than other mineral fillers. Cenospheres are unique free flowing powders composed of hard shelled, hollow, minute Spheres. A small proportion of the pulverized fuel ash (PFA) produced from the combustion of coal in power stations is formed as Cenospheres. Cenospheres are made up of silica, iron and alumina. Cenospheres have a size range from 1 to 500 microns with an average compressive strength of 3000+ psi. Colors range from white to dark gray. They are also referred to as microspheres, hollow spheres, hollow ceramic microspheres, micro balloons, or glass beads.

Nylon 6 – CS composite is less studied area and there is wide scope for research scholar to explore it in various automobile applications. The use of Cenosphere in the production of composite can turn the industrial waste into industrial wealth. This also solves the problem of storage of fly ash as well as brings down the product cost.

Continuous accumulation of fly ash during coal burning in power plant is one of the alarming environmental problems. The amount of continuously producing ash is much higher than its consumption and ash dump is continued to expand. But at the same time some unique properties of Cenospheres obtained from fly ash provides prospects for their use in many applications like ceramics, plastics and construction.

II. MATERIALS AND METHODOLOGY

A. *Materials:*

Polymeric matrix material Nylon 6 (Grade: M28RC, Manufacturer: GSFC) was procured from GSFC, Vadodara. The MFI of Nylon 6 is 28gm/cc. The filler Cenosphere (Grade: CS100) was procured from Petra Buildcare Products, Bhavnagar). Particle size of Cenosphere is 5-100µm. The general properties of Cenosphere are:

- **Size range :** 5 - 500 micron
- **Wall Thickness :** 2 - 5 micron
- **Color :** White, Off-white or Grey
- **Bulk Density :** 0.3 - 0.6 g/cc
- **Melting Point:** 1250 - 1450 ^{0}C
- **Moisture Absorption :** < 2.5%
- **Coefficient of thermal conductivity :** 0.09W/mK
- **Specific Heat :** 0.28 Cal/g ^{0}C
- **Hardness :** 5 - 6 Mohr scale
- **Loss On Ignition :** 2% maximum
- **Solubility in Water :** Negligible

The chemical composition of Cenosphere is shown in table I.

TABLE I. CHEMICAL COMPOSITION OF CENOSPHERE

Chemical Composition	**Wt.%**
SiO_2	55-61
Al_2O_3	26-30
Fe_2O_3	4-10
CaO	2-6
MgO	1-2
Na_2O, K_2O	0.45 - 0.55
CO_2 Gas	70%
N_2 Gas	30%

B. Composites and Specimen Preparation:

Nylon 6 – Cenosphere composites were prepared by Co-rotating Twin screw extruder (Make: SPECIFIC ENGINEERING & AUTOMATES) in processing laboratory, HLC, CIPET, Ahmedabad.. L:D ratio of screw is 40:1 and screw diameter is 21 mm. The temperature range used was 180-220 °C. As nylon 6 is hygroscopic material, it was predried at 85 °C for approximately 3 hours to remove moisture in an oven before compounding. Cenosphere was also predried at same conditions to remove moisture. This is necessary to have void free samples. 3 batches of untreated composites were prepared as shown in Table 2.

TABLE II. BATCH COMPOSITION OF PA6 AND CS (UNTREATED)

Batch (3 Kg)	Composition
PA6N	Nylon-6+Cenosphere 0Wt%
PA6CS10	Nylon-6+Cenosphere 10Wt%
PA6CS20	Nylon-6+Cenosphere 20Wt%
PA6CS30	Nylon-6+Cenosphere 30Wt%

The test specimens for various tests were prepared by using Automatic Injection Molding Machine (Make: ELECTRONICA, Model: ENDURA 90) in Processing Laboratory, CIPET, Ahmedabad. Before loading the material in the hopper, the material was predried for about 3 hours at 85 °C to remove moisture which eliminates voids in the samples. The injection molding was carried out at 230 - 275 °C and different test specimens like dumbbell, bar (3 mm and 6 mm thickness) and disc were prepared.

C. Characterisation Techniques:

Various instruments were used to evaluate the mechanical properties of Nylon 6/Cenosphere composites. Tensile strength was evaluated at laboratory conditions using Universal Testing Machine (Make: P.S.I. Sales P. Ltd)) as per ASTM D 638 method with a crosshead speed of 50 mm/min. Flexural strength and modulus were tested by AUTOGRAPH (AG-IS) according to ASTM procedure D 790. The testing speed was 2 mm/min and the span length was 50mm. Impact strength was measured by impact tester (CEAST, Resil Impactor) at ambient condition according to ASTM D 256. Specimens for impact strength were notch cut by CEAST notch cutter before testing. Rockwell Hardness values were measure by ASTM D 785 (R scale) with 1/2" ball indenter and 60 Kg load using Rockwell hardness tester (Make: P.S.I.SALES (P) LTD). These tests eres carried out at testing laboratory, CIPET, Ahmedabad. Abrasion resistance test was measured by TABER abraser 5131 according to ASTM D 4060 with 500 gm load and CS-10 abrading wheel at testing laboratory, CIPET, Bhopal.

III. RESULTS AND DISCUSSION

A. Flexural strength and Flexural modulus

Fig. 1 and 2 shows the effect of Cenosphere concentration on Nylon 6 for untreated composite samples. Both Flexural strength and modulus increase with Cenosphere concentration as Cenosphere increases stiffness of the composites. At 10% CS loading flexural strength increases at increased rate then it increases with slow rate. Flexural modulus increases sharply with increase in CS content and it almost doubles at 30% loading of CS. This is due to the increased stiffness imparted by Cenosphere.

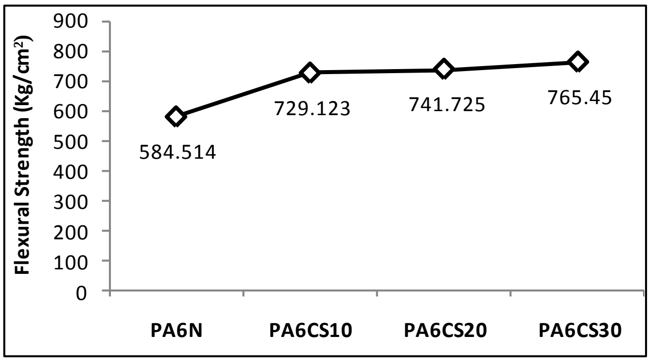

Figure1: Effect of CS concentration on Flexural Strength of PA6/CS composites

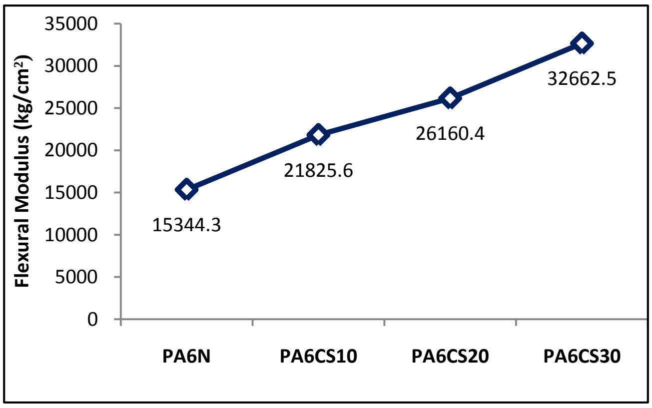

Figure 2: Effect of CS concentration on Flexural Modulus of PA6/CS composites

B. Tensile strength

Fig. 3 shows the effect of unmodified CS on tensile strength at yield of PA6/CS composites. As CS content increases tensile strength decreases slightly, but not drastically. This reduction may be due to low interfacial bonding between filler and matrix. This is because, as CS loading increases the interfacial area also increases, worsening the interfacial bonding between filler and matrix.

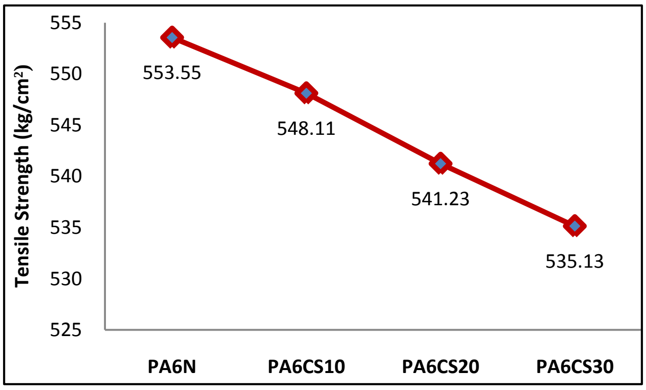

Figure3: Effect of CS concentration on Tensile Strength of PA6/CS composites

C. Impact strength

As shown in fig. 4, Izod impact strength is reduced drastically with increase in CS content. With untreated case, it reduces up to 50% of virgin Nylon 6. CS content reduces ability of matrix material to absorb energy on sudden load. Here, reduction in impact strength is due to reduction in effective cross section of matrix and increase in stress concentration. There may be poor stress transfer between matrix PA6 and filler CS particles. Lack of interfacial adhesion between filler and matrix may also be the reason.

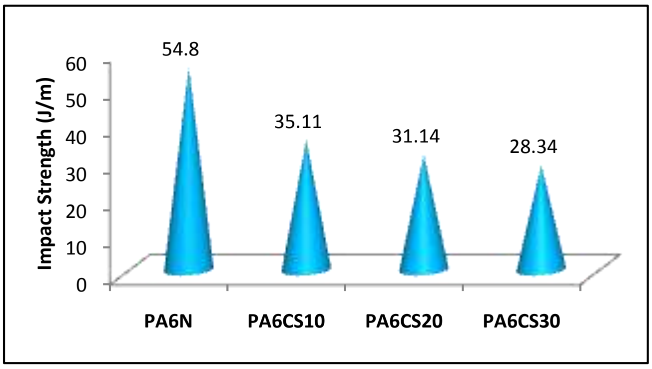

Figure 4: Effect of CS concentration on Izod Impact Strength of PA6/CS composites

D. Rockwell hardness

Fig. 5 shows that as CS concentration increases Rockwell hardness of PA6-CS composites (unmodified) also increases. Hardness is the measure of the modulus of elasticity. With increase in filler concentration modulus of composites also increases which results in increase in hardness value of composite. Increase in hardness is also due to the hard and rigid nature of Cenosphere particle. CS has hardness value of 5-6 Moh scale, far better among mineral fillers, which imparts this property.

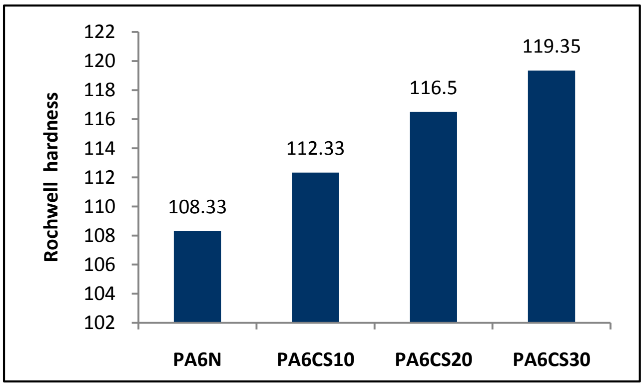

Figure 5: Effect of CS concentration on Rockwell Hardness of PA6/CS composites

E. Abrasion Resistance

Fig. 6 shows the removal of material in mg on abrasion with increase in CS concentration in PA6/CS composites. Weight loss in mg decreases with increase in CS content. This indicates abrasion resistance of PA6/CS composite increases with increase in CS content. This is due to the hard and rigid nature of Cenosphere. Hardness of Cenosphere is 5-6 Moh scale which renders composites abrasion resistant. About 20% increase in abrasion resistance is found on every 10% increase in Cenosphere content.

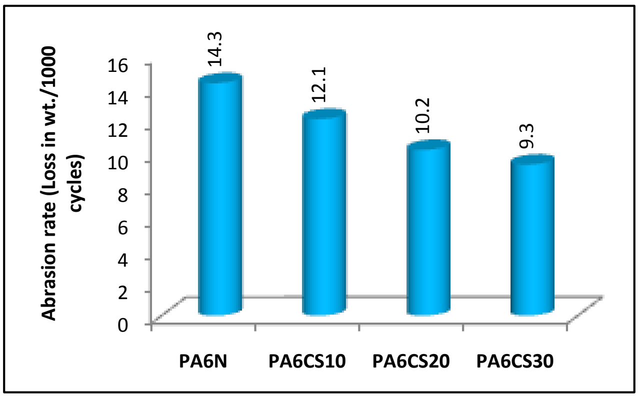

Figure 6: Effect of CS concentration on Abrasion Resistance of PA6/CS composites

IV. CONCLUSION

- Very good improvement in Flexural strength and Flexural modulus is found with increase in CS content. At 30% CS content flexural modulus increases more than double compared to virgin Nylon 6.
- Tensile strength decreases marginally with increased CS content.
- Impact strength of composites decreases drastically up to 50% of virgin Nylon 6 at 30% CS content.
- Hardness and abrasion resistance of unmodified PA6/CS composites increases with CS content due to inherent hardness of Cenosphere.

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