International Journal on Recent and Innovation Trends in Computing and Communication ISSN: 2321-8169
Volume: 3 Issue: 7 4714 - 4718

Effect of Untreated Wollastonite on Mechanical Properties of Nylon6

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Abstract— Nylon-6/untreated Wollastonite composites were prepared with different loading of 15, 25 and 35 % w/w of Wollastonite (acicular ratio-15-20%) by co-rotating twin screw extruder. Mechanical properties of injection molded specimens of Nylon-6/ untreated Wollastonite composites were evaluated. Mechanical properties like flexural strength, flexural modulus, tensile strength, impact strength, hardness and abrasion resistance were evaluated for these composites. Wollastonite improves flexural modulus, flexural strength, hardness and abrasion resistance of the composites. The results suggest application of Nylon-6/Wollastonite in automotive parts, electric motors, gears, power tool housings etc. Due to fibrous nature, Wollastonite replacing short milled glass fibers for both thermoplastics & thermo-sets and short-fiber Asbestos which are hazardous to human health as well as difficult to handle.

Keywords- *Wollastonite; Nylon-6; Mechanical Properties; Flexural Strength; Flexural Modulus; Tensile Strength; Impact Strength; Hardness; Abrasion Resistance*

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I. INTRODUCTION

NYLON-6 is widely used in engineering fields due to its excellent properties such as easy process ability and good mechanical characteristics. However, its low heat distortion temperature and water absorption restrict its applications [1-6]. Wollastonite is used as reinforcing filler in Nylon-6 because of its low oil and moisture absorption, high brightness, acicularity, and availability-which reduces the ultimate cost of the product.

Commercial grades of Wollastonite (Calcium Meta Silicate - CaSiO3) are typically high in purity because most ores must be beneficiated by wet processing, high-intensity magnetic separation, and/or heavy media separation to remove accessory minerals. The minerals most commonly found associated with Wollastonite are calcium carbonate, calcium magnesium silicate and calcium aluminum silicate.

The reaction has been as follows:

$$SiO_2 + CaCO_3 = CaSiO_3 + CO_2$$

Silica + Limestone = Wollastonite + Carbon dioxide

Wollastonite is hard, white, and alkaline (pH 9.8). It is the only naturally occurring, nonmetallic, white, needle-like natural mineral with a specific gravity of 2.9, Mohs hardness of 4.5 and refractive index between 1.63 and 1.67. It is widely used with Polyamide 6 & 66, Polypropylene (PP), Polycorbonate (PC), Polyurethane (PU), PEEK, Polystyrene (PS), Thermoplastic elastomers (TPE) etc.

Addition of Wollastonite to Nylon-6 eliminates moisture from hygroscopic material, improves stiffness due to its higher mohs scale of 4.5; surface appearance because of its white color; surface reflectivity as it has refractive index in the range of 1.63-1.67; excellent fire and smoke suppressant properties as Wollastonite is a natural mineral filler

II. MATERIALS AND METHODOLOGY

A. *MATERIALS*

Polymeric matrix material Nylon-6 (Grade: M28RC, Manufacturer: GSFC) for this work was procured from GSFC, Vadodara. The MFI of Nylon-6 is 28gm/cc. Wollastonite (Grade: KEMOLIT-A 60) was procured from Amgeen Minerals, Ahmedabad. L: D ratio of acicular Wollastonite is 15 (fiber length-75 µm & fiber diameter-5µm).

The general properties of Wollastonite are:

Table: 1- Physical Data Of Wollastonite

1.	Color	Brilliant White
2.	Luster	Pearly
3.	Brightness	96-98%
4.	Hardness	4.5%
5.	Oil Absorption	25-30lbs/100
6.	Ph of 10% Slurry (fresh prepared)	9.0
7.	Solubility in Water	0.00095 (gm/100cc)
8.	Melting Point	1540° C
9.	Co-Efficient of Expansion (mm/^{O}C)	6.5x106
10.	Thermal Conductivity (btu/hrft2/of/in)	0.87
11.	Refractive Index	1.627
12	Specific Gravity	2.9
13.	Bulk Density	855 kg/m^3
14.	Bulking Value (Gal/Ib)	0.0413

Table: 2 - Chemical Composition Of Wollastonite

ISSN: 2321-8169
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1	Calcium Oxide	Cao	46.5
2	Silica	Sio2	49.7
3	Iron	Fe2o3	0.4
4	Alumina	Al2o3	0.6
5	Loss On Ignition	Loi	2.66

B. COMPOSITE AND SPECIMEN PREPARATION

Nylon-6/Wollastonite 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 pre-dried at 85 °C for approximately 3 hours to remove moisture in an oven before compounding. Wollastonite was also pre-dried at same conditions to remove moisture, which is necessary to have voided free samples. Three batches of untreated composites were prepared as shown in Table 3.

Table 3: Batch Composition

BATCH	COMPOSITION
PA6N	Nylon-6 + Wollastonite 0 Wt%
PA6W15	Nylon-6 + Wollastonite 15 Wt%
PA6W25	Nylon-6 + Wollastonite 25 Wt%
PA6W35	Nylon-6 + Wollastonite 35 Wt%

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 pre-dried 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.

III. CHARACTERIZATION TECHNIQUES

Various testing instruments were used to evaluate the mechanical properties of Nylon-6/Wollastonite 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 procedure ASTM 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 12.5mm ball indenter and 60 Kg load using Rockwell hardness tester (Make: P.S.I.SALES (P) LTD). These tests were carried out at testing laboratory, CIPET, Ahmedabad. Abrasion resistance test was measured by TABER abrasion tester 5131 according to ASTM D 4060 with 500 gm load and CS-10 abrading wheel at testing laboratory, CIPET, Bhopal.

IV. RESULTS AND DISCUSSION

Flexural Strength: As shown in Fig. 1, flexural strength of the composite was increased with increasing Wollastonite loading in Nylon-6. At the initial stage of 15% Wollastonite loading, there was increase up to 22.85% in strength; for 25% loading gradual increase up to 34.38% and then it was suddenly decreased for 35% concentration of Wollastonite with respect to 25% loading.

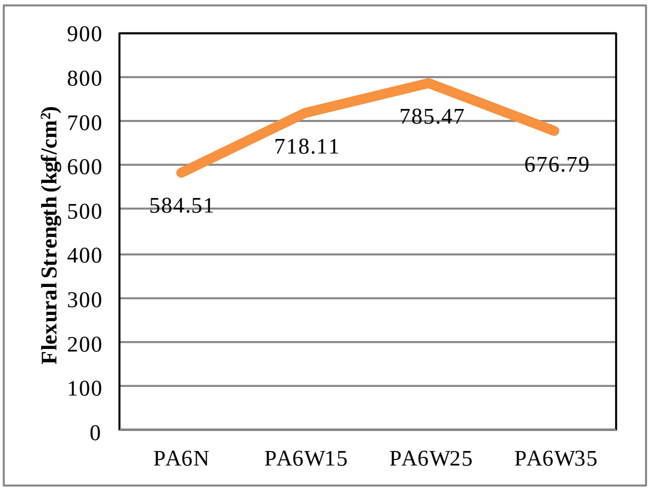

Fig. 1: Effect of Wollastonite concentration on Flexural Strength of NYLON-6/Wollastonite composites

Flexural Modulus: Flexural modulus of composite increased with higher filler concentration due to increase in stiffness of composites, which depicted in Fig. 2. 119.97% increment in case of 35% concentration of untreated Wollastonite was measured.

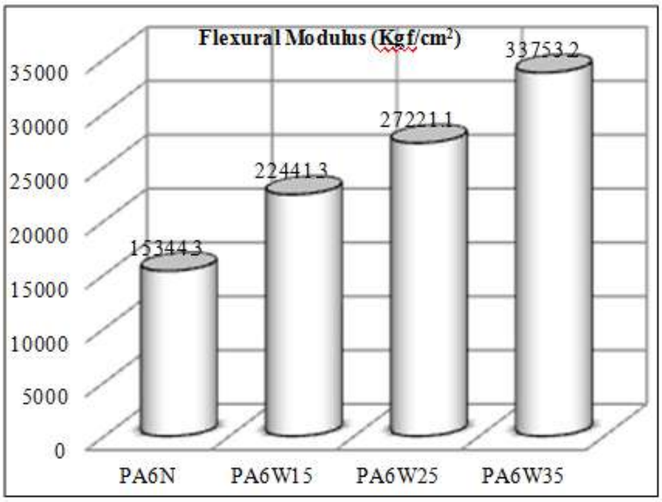

Fig. 2: Effect of Wollastonite concentration on Flexural Modulus of NYLON-6/ Wollastonite composites

Tensile Strength: Tensile strength of composites at yield point is shown in Fig. 3. The tensile strength of the composite was increased with increasing Wollastonite concentration (particularly for 35% loading). Wollastonite increases the stiffness of the composite which results into increasing the tensile strength, while the elongations of the composites were reduced because as the filler concentration increased the composite becomes more rigid.

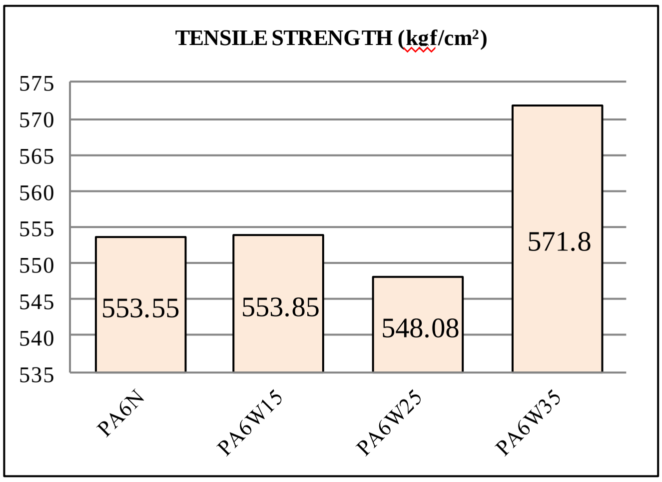

Fig. 3: Effect of Wollastonite concentration on Tensile Strength of NYLON-6/ Wollastonite composites

Impact Strength: Impact strength of composites was decreased with increasing of mineral filler Wollastonite in Nylon-6 matrix which is clearly shown in the Fig. 4. The Izod impact value was reduced in the range of 36.61 to 40.9% in case of 15%, 25% and 35% loading of untreated Wollastonite. This was due to reduction of ability of composite to absorb energy and thus reducing the toughness.

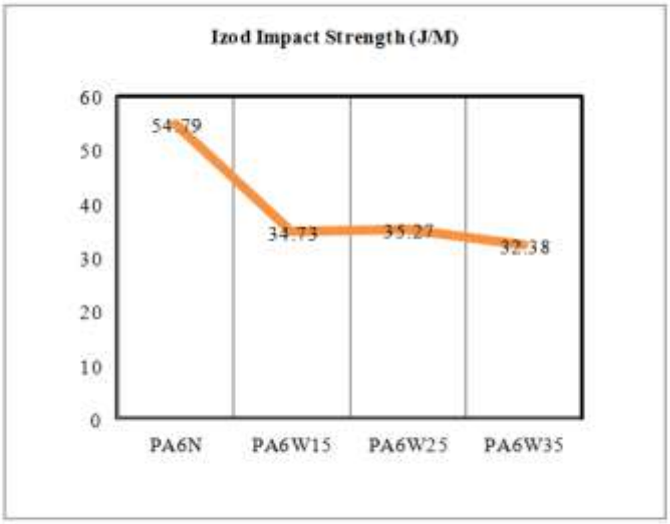

Fig. 4: Effect of Wollastonite concentration on Izod Impact Strength of NYLON-6/ Wollastonite composites

Rockwell hardness: Rockwell hardness of the composites was increased with increasing concentration of Wollastonite. Hardness of composite was increased due to Wollastonite's hardness (4.5 mohs scale). From the Fig. 5, it was cleared that hardness increased gradually with increment of Wollastonite content. 15.84% increment of hardness of untreated Wollastonite with respect to Nylon-6 was found.

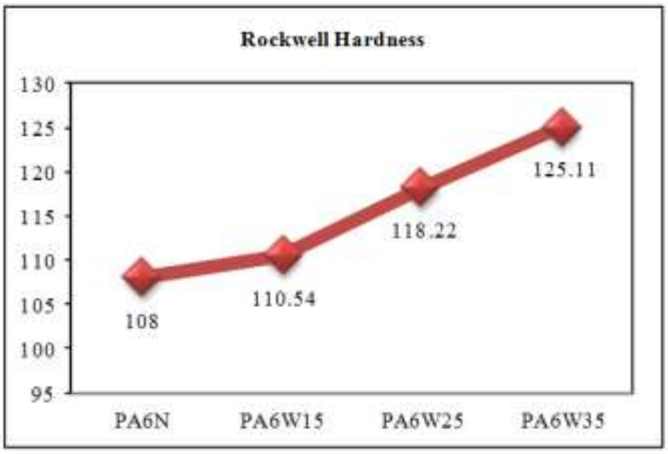

Fig. 5: Effect of Wollastonite concentration on Rockwell Hardness of NYLON-6/ Wollastonite composites

Abrasion Resistance: Abrasion of the material is related to its hardness and so the material loss during abrasion test was reduced from 14.180 mg. to 12.784 mg. As shown in the Fig. 6, weight loss in case of virgin Nylon-6 sample was gradually reduced by increasing concentration of Wollastonite in matrix.

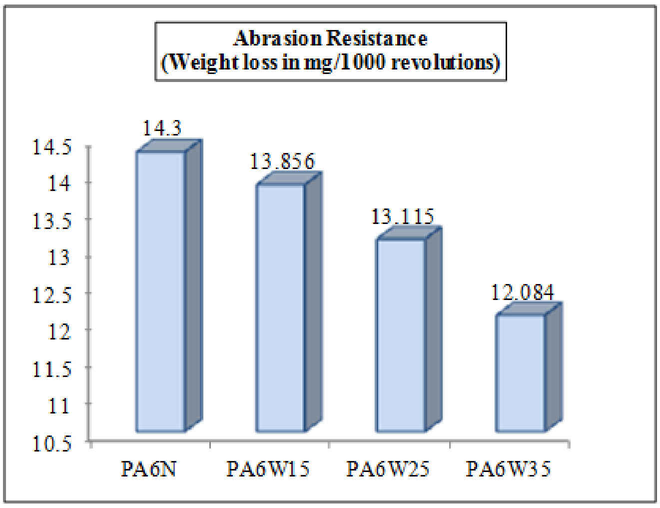

Fig. 6: Effect of Wollastonite concentration on Abrasion Resistance of NYLON-6/ Wollastonite composites

V. CONCLUSION

- Flexural strength and modulus of untreated composite were increased with increased filler concentration due to stiffness in the composite; Flexural moduli have remarkable increments.
- Tensile strength of composites was increased with increasing Wollastonite content due to the structure of composites became more crystal and stiff because of inherent properties of Wollastonite to make the composite more hard and stiffer.
- Impact strength was drastically reduced because of stiffness property of composite.
- Due to hardness property of Wollastonite, hardness of composites also increased.
- Abrasion resistance was increased as concentration of Wollastonite increase.

ACKNOWLEDGMENT

The authors are thankful to the processing and testing laboratory of CIPET, Ahmedabad as well as testing laboratory of CIPET, Bhopal for providing necessary supports to carry out this research work.

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