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PROCESS**

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Abstract

The effect of three commercial inorganic additives supplied by Ciba Speciality Chemicals, Germany namely, Irgaguard B 5000 (carrier of Ag/ Zn zeolite), Irgaguard B7000 (carrier of Ag / Zn glass) and Irgaguard 1000 (triclosan) on the properties of polypropylene fibers was studied. These additives 0.1- 2 %(w/w) concentrations were well mixed to preheated isotatic PP chips and added into the hopper tanks of a Fourne' double extruders machine together with purged nitrogen gas and melt extruded at 250°C to produce the continuous fibers.

Characterization of the produced PP / Irgaguard composite fibers was carried out by Thermo Gravimetric Analysis (TGA) and Differential Scanning Calorimeter (DSC) to follow up the thermal stability of fibers, determination of the melting point and the percentage crystallization of the spun fibers. Mechanical properties of the composite fibers including count number, tensile strength, elongation, modulus and tenacity were analyzed and compared to the PP control. Transmission scanning electron microscopy (TEM) was studied to investigate the morphology of the composite fibers. These PP/ Irgaguard composite fibers have shown permanent antibacterial activity which was tested against *E.coli*, *S.aureus* and the antistatic property was determined.

Key words: isotatic polypropylene, Irgaguard B additives, melt extrusion machine, properties.

Introduction

Polypropylene possesses an economical advantage such as low price and is one of the most widely used all over others synthetic fibers in the textile industry. As it is expected that synthetic fibers do not require antibacterial activity, since the resistance to bacteria is stronger than that of natural fibers. It is easy for a microorganism to attack the main chains of polymers such as PP because they contain methyl groups. There is a need to impart PP with antibacterial activity¹

because it is used for sanitary applications such as filters, diapers, surgical masks and hygienic bandages.

Many commercial fillers containing silver and zinc, are available in the International markets based on certain carrier materials such as zeolite, glass etc... where the sodium ions present in zeolites are substituted by silver. These substituted antimicrobials zeolites are incorporated into many commercial polymers such as polyethylene, polypropylene and polyamide at levels of 1-3% to improve the hydrophilic and physical properties.

Literature review revealed that Struzczyk² et al have studied the mechanical properties and the bioactivity (antibacterial and antifungal properties) for PP, PA and PET modified by Irgaguard B 7000 or cavinon additives. Yoon et al³ have prepared siloxylated polypropylene fibers composed of polypropylene (PP) and alumino siloxane (AS) which are synthesized by the melt blending followed by spinning. The effects of blend compositions on the thermal behaviors, surface and tensile properties of PP/AS blend fibers are investigated. It is confirmed that PP could be siloxylated with AS due to the mechanical compatibility. Sinta et al⁴ have studied polypropylene reinforced with short glass fibers and which are modified with precipitated nano silica (pns) by melt mixing. The mechanical properties of glass fibers / PP composite can be improved by the incorporation of nano silica. The maximum reinforcement for glass fibers-pn s/PP composite was found to be at a fiber loading of 30 wt. %. The storage modulus of 30 wt. % glass fibers –1% pns/PP composite is found to be the same as that of 50 wt. % glass fibers /PP composite. The crystallization temperature of PP is slightly enhanced in the presence of glass fibers and nano silica. Thermogravimetric studies showed that the thermal stability of PP is also improved by the addition of glass fibers and nanosilica. The effect of glass fibers on improvement the mechanical properties of PA6 is investigated⁵.

Wei et al⁶ have synthesized Titanium dioxide / polypropylene fibers by melt-compounding and sputter coating respectively. The use of titanium dioxide in polypropylene fibers as an example to illustrate that a great care is needed in order to obtain an even distribution of nano particles, whether it is within the bulk of a fiber or on its surface. Of the two methods used to incorporate titanium dioxide nano particles into polypropylene fibers, melt-compounding caused the nano particles to be highly aggregated and coverage of the fiber surface with titanium dioxide was

poor. The coverage of the sputter coated polypropylene fiber surfaces by titanium dioxide was much better, although the nano particles still appeared quite extensively aggregated.

Yeo et al ⁷ have produced polypropylene /silver nano composite fibers for the attainment of permanent antibacterial activity to common synthetic textiles. The fibers are melt-spun by co-extrusion of polypropylene (PP) and PP/Ag master-batches using general conjugate spinning technique. The sheath-core bicomponent fibers of the two types are melt-spun by co-extrusion of polypropylene (PP) and PP/Ag master-batch. DSC results have shown that the crystallinity of the spun fibers with the added silver nano particles slightly decreased or is maintained as previously stated. The diffraction peaks of the silver crystals in polypropylene are grown up with increasing silver content in the two processes, the first spinning and the second spinning. The SEM results showed that the silver nano particles in fibers have relatively good dispersion. The results of antibacterial test have shown that the fibers containing silver nano particles in core part had not nearly significant antibacterial activity. However the fibers having silver in sheath-part showed excellent antibacterial effect.

Joshi et al ⁸ have studied composite filaments from nano clay reinforced polypropylene. The development of tenacity, high modulus monofilaments from polypropylene/ clay nano composite has been investigated. Pure sodium montmorillonite nano clay was modified using hexadecyl trimethyl ammonium bromide (HTAB) via an ion exchange reaction. Nano clay reinforced PP nano composites could be spun and drawn successfully for 0.5, 1.0, and 1.5 wt. % of the modified clay loading. Beyond 1.5 wt %, the spinning of fibres was poor. The 0.5 and 1.0 wt % reinforced PP/ modified nano clay composite filaments show significant increase in tenacity (30%) as well as modulus (100%), compared to neat PP filaments. The SEM studies indicate good dispersion of modified clay in the PP matrix. Dastjerdi et al ⁹ have investigated the effect of various blend ratios of the prepared master batch containing Ag/TiO₂ nano composite on the properties of bioactive continuous filament yarns. This research has been started from the modification of polymer powder as a common by-product of petrochemical companies and preparing master batch. The development of bacteriostatic filament yarns has been realized from mixing of virgin PP granule and the prepared master-batch. The processing of these starting materials and the characteristics of the

produced samples (fiber to fabric) has been investigated. Noher et al ¹⁰ have employed quaternary ammonium compounds as antibacterial melt additives in an extrusion process of nonwoven polypropylene fibers. Commercial PP melt additives produced by Ciba Specialty chemicals ¹¹ are used such as Irgastat P which is useful as antistatic agent and Irgaguard B1325, 0.4% is effective as antimicrobial against E.Coli . A review on the recent developments in antimicrobial finishing of textiles including metals and metal salts, chitosan, triclosan, zeolites and others are reported ¹². Williams et al ¹³ have incorporated into synthetic polymer, silver zeolite, metallic silver or silver complexed with polyhexamethyl biguanide and zinc which can be complexed with silver and zeolite. Broda et al ¹⁴ have investigated the influence of two organic pigments and two flame retardants on the structure of polypropylene fibers. It was found that by spinning at low velocities in presence of pigment , a highly crystalline structure is formed.

Thus, polypropylene fibers can be functionalized by the use of well selected additives. Use of the inorganic commercial additives such as Irgaguard products in the melt extrusion-spinning process is suggested in this article to improve polypropylene properties. These additives are well mixed at the starting of the process with the polymer and then melt extruded.

In the present investigation, three inorganic products from Ciba Speciality Chemicals are chosen namely Irgaguard B 5000 (Ag/Zn zeolite) , Irgaguard B 7000 (Ag/Zn glass) and Irgaguard 1000 (triclosan) which are mixed with selected varying concentrations 0.1-2 % wt with PP chips and are added to purged nitrogen atmosphere , in the hopper tanks followed by the melt extrusion process using a bi extrusion Fourne' machine at 250⁰ C. Characterization of the produced fibers is carried out by TGA and DSC to study the thermal stability of the composite fibers and determination of the melting points and the percentage crystallization of the produced fibers. Effect of Irgaguard compounds on the mechanical properties of the produced PP composite fibers including denier, tensile strength, elongation, modulus and tenacity is discussed. The antibacterial and antistatic properties of the produced fibers are tested and reported .TEM is investigated to observe the morphology of PP/Irgaguard composite fibers.

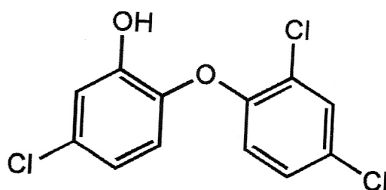
Experimental

Materials

Isotactic polypropylene chips were supplied from Exxon Mobil™ PP 3155, USA, specific gravity 0.902, tenacity 3.1 gm/denier. Commercial Irgaguard compounds including Irgaguard B 5000, Irgaguard B 7000 and Irgaguard 1000 were supplied as a gift from Ciba Specialty Chemicals, Germany and the nonionic agent Triton X100 was purchased from Merck.



Scheme 1 Chemical structure of Triton X100



Scheme 2 Chemical structure of Irgaguard 1000
(triclosan 2,4,4'-trichloro-2-hydroxydiphenylether)

Table 1 Antimicrobial commercial additive for polypropylene

| Commercial Additives | Producer | Composition | Metal content | |
|----------------------|--------------------------|-----------------|---------------|------|
| | | | Ag % | Zn % |
| Irgaguard B 5000 | Ciba Specialty Chemicals | Zeolite(Ag,Zn) | Undisclosed | |
| Irgaguard B 7000 | Ciba Specialty Chemicals | Glass (Ag, Zn) | Undisclosed | |

Spinning process

The French machine is used at the Textile College of NCSU for the present research. It is a Fourne' double component melt extruders (Fig 1). A good mixing of vaccum preheated for one hour at 70° C isotactic polypropylene (PP) chips and selected additives of Irgaguard compound , 0.1-2% concentrations is done in a glass container and is added in the hopper tanks of the machine in nitrogen atmosphere , which is guided through an automatic pressure control booster pump at a constant 8 rpm rate and is metered with geared pumps. The extrusion process was conducted using a two screw extruders at 400 psi with a 22 mm screw diameter of L/D 20:1 , having three static mixers with gradient temperatures, the first extruder(zone one 220° C , zone two 230° C , zone three 240° C) and the second extruder was working

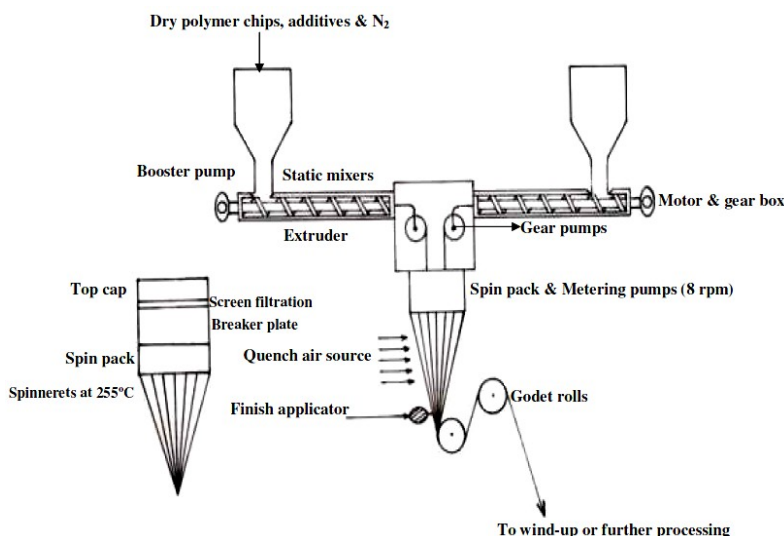
at the same previous zones temperatures. A spin pack was designed for a multifilament fibers spinning (36filaments/fiber) and equipped with mesh filtration screens. The fibers were cooled at room temperature and finished by luroil PP, L425 lubricant (Goulston Chemical Co. USA) and drawn at 800m/min (200,400,800m/min for godets 1, 2, and 3 successively) and having 3.55denier /filament.

Differential Scanning Calorimeter

Compensated Differential Scanning Colorimeter (DSC Perkin-Elmer Model 7) equipped with a cooler was used under nitrogen atmosphere. All samples were heated from -40 to 200 ° C at 20 ° C /min .The onset melting temperature was obtained from the intercept of the baseline and the maximum tangent of the corresponding endothermic peak. From the DSC graphs, melting temperatures (T_m) of the composite fibers were obtained and the apparent fusion enthalpies were calculated from the area of the endothermic peak. The percent crystallinity of polypropylene was evaluated using the following equation

$$\text{Percentage Crystallinity} = \frac{\Delta H_f \times 100}{\Delta H_f^0}$$

Where ΔH_f is the enthalpy heat of fusion of PP fibers, ΔH_f^0 is the enthalpy of heat of fusion of 100% crystalline PP taken as 209 J/gm^{15, 16}.



.Fig.1 Bicomponent melt spinning machine

Thermo Gravimetric Analysis (TGA)

TGA was measured for PP control and PP/ Irguard composite fibres using a Shimadzu TGA -50H apparatus of Cairo Univ.. The percentage weight change versus temperature was evaluated at a scan rate of 15 °C/min. over a temperature range 25 -800° C in nitrogen atmosphere

Mechanical properties

The fiber count number (denier) was done at NCSU testing laboratory by the stein method according to ASTM-D1907 after conditioning the fibers at 20 °C and 65% RH for 24 hrs. The tensile strength, percentage strain, fiber modulus , fiber tenacity were done according to ASTM-D2256 Q test /5- CRE tests and were recorded for ten measurements per sample and their average results was calculated .

Antibacterial analysis

A modified AATCC 100 test method was adopted for measuring the antimicrobial activity of PP/ Irguard composite fibers ¹⁷. Two strains of bacteria Escherichia coli and staphylococcus aureus were used. One piece of fiber string (20 cm; 0.31 mg) was placed in a 1.5 ml micro centrifuge tube and 200 µl of saline containing 10⁷ CFU / ml (log 7) of the organism was added in the tube to completely cover the fiber and was incubated for 24 hrs at the appropriate temperature for the inoculated culture. After 24 hr, the LBG or YM plates were spread with the supernatant using a spiral platter (Model 4000, Spiral Biotech). After appropriate incubation, the bacterial (37 °C) colonies were counted. Plate counts were determined by an automated spiral plate reader (Q count, Spiral Biotech.)

The reduction in bacteria growth count was calculated compared to PP control (without any additive) as follows:

$$\% \text{ reduction of bacteria} = (A - B / A) \times 100$$

A: number of bacterial colonies for the control

B: number of bacterial colonies for PP/ nano metal fibers

Antistatic tests

The tests were performed using the linear antistatic instrument as in our previous article ¹⁸ and that at of Seyam¹⁹.

Transmission Electron Microscope (TEM)

The melt-spun fibers samples were observed under the Transmission Scanning Electron Microscope at NRC , Cairo (JEOL-JEM 1230 , made in Japan) which is operating up to 120 KV and 600 000 X magnification . The sample was loaded on the copper grid which is coated with a thin amorphous carbon film.

Results & Discussion

Mechanical properties

Addition of low concentrations 0.1% to 0.3% Irgaguard B 5000 or Irgaguard 7000 to PP during the melt extrusion greatly modifies PP properties.

Table 2 shows that low concentrations 0.1-0.3 % addition of Irgaguard 5000 to PP doesn't change the tensile strength nor the elongation of PP composite fibers which are approximately constant at an average of 311.8 gm force/ fiber and 259.4 mm respectively. The average fiber modulus highly 29% increased by the addition of 0.3% Irgaguard 5000 compared to PP control.

Complexation of 0.1% Zn to PP/ 0.1% Irgaguard 5000 slightly increases the tensile strength by 2.7%, the average fiber modulus by 24.3% compared to PP control and 10.5% compared to 0.1% Irgaguard 5000 only and a slight increase in the elongation (3.5%).

Compounding of low concentration 0.1-0.3% of Irgaguard 7000 to PP increases the average fiber modulus by 24.6 % , slightly increases the tensile strength and the elongation 2.2 and 1.4 respectively compared to PP control.

Addition of 0.1% Zn to PP /0.1% Irgaguard 7000, does not change significantly the mechanical properties compared to PP/0.1% Irgaguard 7000 , where the fiber modulus is constant at 14.84 gm/denier , the elongation increased 6% and the tensile strength slightly decreased 1.4%. The above composite fibers increased the modulus 24.6 gm/denier and increased slightly the elongation and the tensile strength compared to the control. In general, addition of low concentration of Irgaguard compounds 0.1-0.3 % and 0.1% Zn to PP, increases the fiber modulus to a variable degree from 13.4 to 15.312 gm/denier compared to PP control (11.91gm / denier) as well as a slight increase in the tensile strength is observed , which indicated the formation of strong composite PP/ Irgaguard fibers.

Differential Scanning Calorimeter (DSC)

Differential Scanning Calorimeter (DSC) thermograms of PP and PP/Irgaguard composite fibers are shown in Table 3 and Figs 2-3 which include the melting points, , the heat of fusion ΔH and the percentage crystallinity. DSC study revealed

that the melting temperature slightly increased by the addition of Irgaguard compounds to PP to a maximum of 2°C by the addition of 0.3% Irgaguard 7000, (165.92°C), compared to 163.8°C for the control. The crystallinity is nearly constant and does not show significant change by the addition of Irgaguard compounds to PP. At low concentrations of Irgaguard compounds and consequently low concentrations of nano metals Ag and Zn content in fibers and at high cooling rate (20°C), these nano particles did not act as nucleating agent in the polymer matrix^{2,13}.

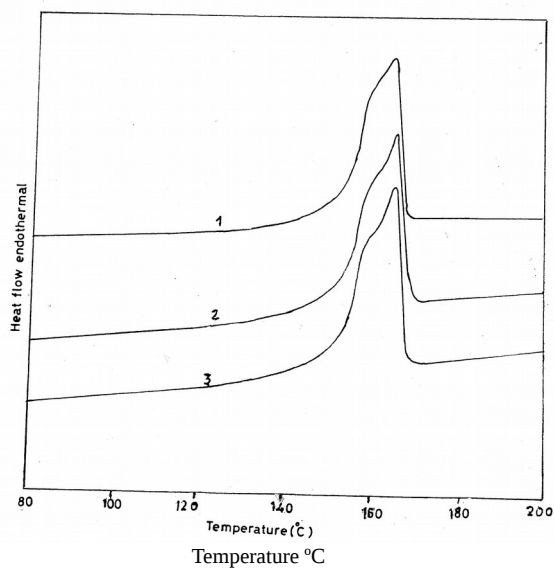
Table 2: Mechanical properties of PP / Irgaguard composite yarns (36 filaments /yarn)

| Sample | Denier (Practice) | Denier(calculated) | Tensile Strength X 10 ⁻³ Kg/cm ² | Elongation mm | Strain % | Fiber Modulus gm/denier | Fiber Tenacity gm/denier |
|--------------------------------|-------------------|--------------------|--|-----------------|----------|-------------------------|--------------------------|
| PP Control | 128 |) 128 (3.55) |) 310.51 (8.63) |) 257.66 (7.16) | 203.58 | 11.91 | 2.43 |
| PP/0.1% Irgaguard B5000 | 129 |) 128 (3.55) |) 281.57 (7.82) |) 259.02 (7.2) | 203.70 | 13.40 | 2.21 |
| PP/0.2% Irgaguard B5000 | 127.6 |) 128 (3.55) | (8.66) 311.6 |) 254.6 (7.07) | 201.2 | 13.57 | 2.43 |
| PP/0.3% Irgaguard B5000 | 128.4 |) 128 (3.55) | (8.66) 311.8 |) 264.43 (7.35) | 208.2 | 15.37 | 2.44 |
| PP/0.1%Irgaguard B5000/ 0.1%Zn | 125.7 |) 128 (3.55) | (8.86) 319 |) 253.51 (7.04) | 210.71 | 14.80 | 2.49 |
| PP/0.1% Irgaguard B7000 | 127 | 3.55)128 (|) 319.41 (8.87) |) 248.51 (6.90) | 202.83 | 15.20 | 2.50 |
| PP/0.2% Irgaguard B7000 | 125.5 | 128 (3.55) | 319.63 (8.88) | 255.22 (7.10) | 204.29 | 14.8 | 2.44 |
| PP/0.3% Irgaguard B7000 | 129 | 128 (3.55) | 317 (8.81) | 274.1 (7.61) | 215.9 | 14.84 | 2.50 |
| PP/0.1%Irgaguard B7000/ 0.1Zn | 128.7 | 128 (3.55) | 314.99 (8.75) | 263.24 (7.31) | 207.28 | 14.84 | 2.46 |
| PP/1%Irgaguard 5000/*DA | 531.8 | 128 (3.55) | 114.93 (3.7) | 93.1 | 73.31 | 11.22 | 0.90 |
| PP/1%Irgaguard 7000/*DA | 524.6 | 128 (3.55) | 125.43 (3.48) | 81.32 | 103.3 | 11.53 | 1.0 |
| PP/2 %Irgaguard B 1000/*DA | 532.5 | 128(3.55) | 149.54 (4.15) | 138.63 | 109.16 | 6.22 | 1.17 |

- *DA, is the nonionic dispersing agent, Triton X100.
- Between brackets are the values per filament.
- All the other values are given for 36 filaments/ yarn.

Table 3 DSC of PP / Irgaguard composite fibres

| sample | Onset M.Pt °C | Peak M.Pt °C | ΔH_f J/gm | crystallinity % |
|---------------------------------|------------------|-----------------|----------------------|--------------------|
| PP Control | 152.4 | 163.8 | 84.93 | 40.64 |
| PP/0.1% Irgaguard B 5000 | 151.64 | 164.4 | 85.57 | 40.94 |
| PP/0.2% Irgaguard B 5000 | 151.44 | 164.21 | 83.89 | 40.13 |
| PP/0.3% Irgaguard B 5000 | 152.07 | 164.4 | 84.28 | 40.33 |
| PP/0.1% Irgaguard B 7000 | 152.39 | 164.73 | 83.71 | 40.05 |
| PP/0.2% Irgaguard B 7000 | 152.31 | 163.69 | 85.18 | 40.76 |
| PP/0.3% Irgaguard B 7000 | 151.87 | 165.92 | 84.85 | 40.60 |
| PP/0.1% Irgaguard B 5000/ 0.1Zn | 152.38 | 165.03 | 84.29 | 40.33 |
| PP/0.1% Irgaguard B7000 /0.1%Zn | 152.2 | 165.81 | 87.10 | 41.67 |

**Fig.2 DSC diagrams of PP / Irgaguard fibres**

1. PP control
2. PP/0.1 % Irgaguard 5000/0.1%Zn
3. PP/0.1% Irgaguard 7000/0.1% Zn

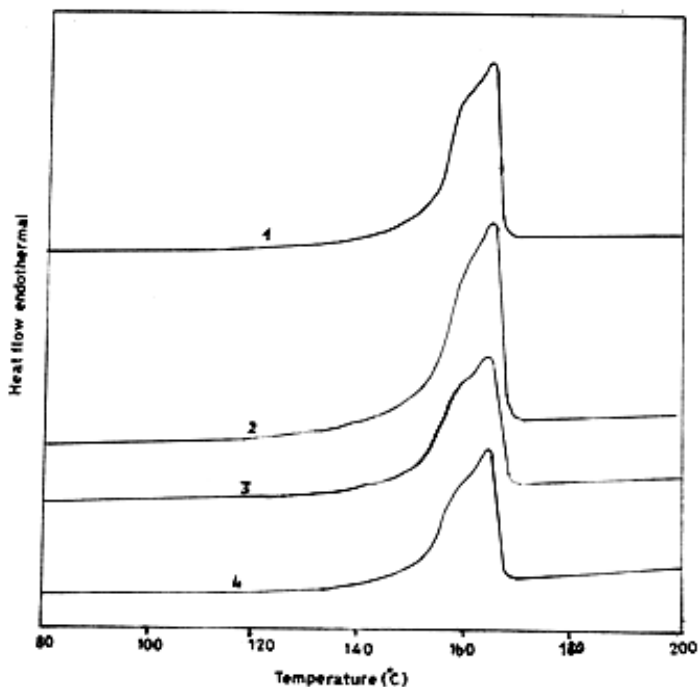


Fig 3 DSC diagrams of PP/ Irguard B 5000 composite fibres

1. PP control
2. PP/0.1% Irguard B 5000
3. PP/0.2% Irguard B 5000
4. PP/0.3 % Irguard B 5000

Thermo Gravimetric Analysis (TGA)

The decomposition temperatures and the residual weights for PP control, PP/Irguard composite fibres are shown in Table 4 and Figs.4. For the PP control and PP/Irguard composite fibres, the onset decomposition of all yarns is approximately 250°C. Addition of 0.3% Irguard 5000 to PP changes the end

decomposition temperature to 462.5°C (6.99% residual wt) compared to 450°C for PP control (1.68 % residual wt).

Incorporation of 0.3% Irgaguard 7000 onto PP, shifted the end decomposition temperature to 462.5°C (8.33% residual wt) .By complexation of the composite PP/0.1% Irgaguard 7000 with 0.1% Zn, the end decomposition temperature is increased to 475°C (14.8% residual wt), thus creating a more thermally stable fibres. The derivative diagrams D TGA; Fig.6 demonstrates that the highest weight reduction occurs at a Tmax temperature, which increased by 18°C, from the control 412°C to 430°C by the addition of 0.3 % Irgaguard 5000 and 7000 , respectively. Addition of 0.1% Zn to PP/0.1% Irgaguard 7000 increases D TGA to 436°C, 24°C higher compared to the control and PP/0.3 % Irgaguard 7000. Addition of 0.1% Zn to PP / 0.1% Irgaguard 5000 decreased the DTGA to 402.5°C which is less than that of the control 412°C (sample 4).

Table 4 TGA, representing the percentage residual weight versus the temperature for the control PP and PP/Irgaguard composite fibres.

| Temperature °C | Residual Weight % | | | | |
|----------------|-------------------|-------|-------|-------|-------|
| | 1 | 2 | 3 | 4 | 5 |
| 300 | 98.24 | 99.13 | 99.17 | 98.63 | 99.54 |
| 350 | 89.55 | 89.55 | 95.24 | 89.83 | 96.53 |
| 400 | 50.42 | 72.92 | 72.48 | 46.11 | 79.16 |
| 450 | 1.68 | 7.68 | 9.46 | 3.70 | 17.56 |
| 500 | 0.64 | 0.68 | 1.13 | 2.31 | 2.77 |

1. control
2. PP/0.3% Irg.5000
3. PP/0.3%Irg.7000
4. PP/0.1% Irg.5000/0.1% Zn
5. PP/0.1% Irg.7000 /0.1 % Zn

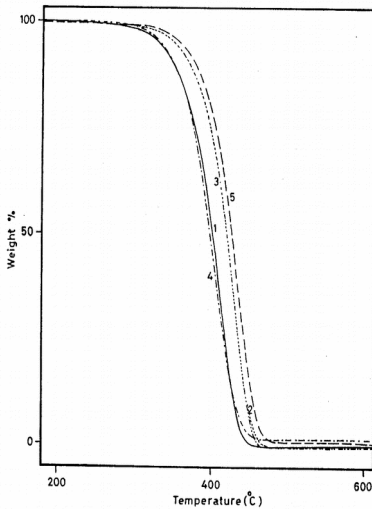


Fig. 4 TGA for PP/ Irguard composite fibres

Antistatic properties

Synthetic fibers create static charges by friction since their moisture regain are very low. Nanotechnology was used for improvement the antistatic properties of textiles by incorporation of nanosized metals and oxides into synthetic fibres because they are electrically conductive materials²⁰. Also silane nanosol improves antistatic properties²¹ as the silane gel particles on the fibers absorb moisture from the air by their amino and hydroxyl groups.

The permanent antistatic additive Irgastat P22 of Ciba Speciality Chemicals¹⁰ was introduced to the market and it works by forming a conductive net work throughout the polymer, and is effective at low humidity levels which results in a permanent antistatic performance of PP fibers.

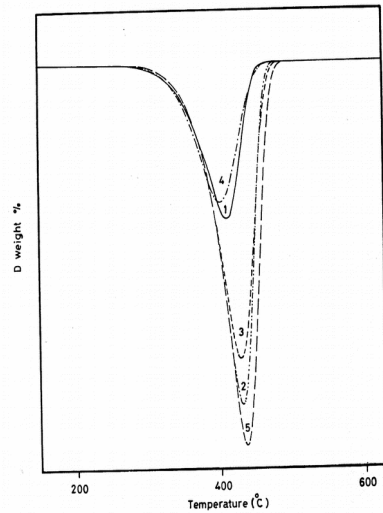


Fig 5 DTGA for PP/ Irguard composite fibres .

The built static charges of the PP/ Irguard composite fibers are measured using the linear tester ^{19,20} of the Textile College, NCSU. Figs 6-8. and Table 5 shows that the potential at the second probe which attains 17 for PP/0.1% Irguard 1000 and -25 V for PP/1% Irguard 5000 compared to -855 V for the control and their decay time are very short 2.11, 0.33 and 1.25 seconds , respectively .These results confirm that the synthesized PP/Irguard composite fibres possess excellent antistatic properties²¹

Table 5 Electrostatic Tests

| Sample | Content | First Probe Potential V | Second Probe Potential V | Calculated Initial Potential (V) | Decay Time (sec) |
|----------------------|-----------|-------------------------|--------------------------|----------------------------------|------------------|
| PP control | nil | -1023 | -855 | -1041 | 1.25 |
| PP/0.1% Irguard 1000 | Triclosan | 95 | 17 | 111 | 0.33 |
| PP/1% Irguard 5000 | Zn, Ag | - 33 | -25 | -34 | 2.11 |

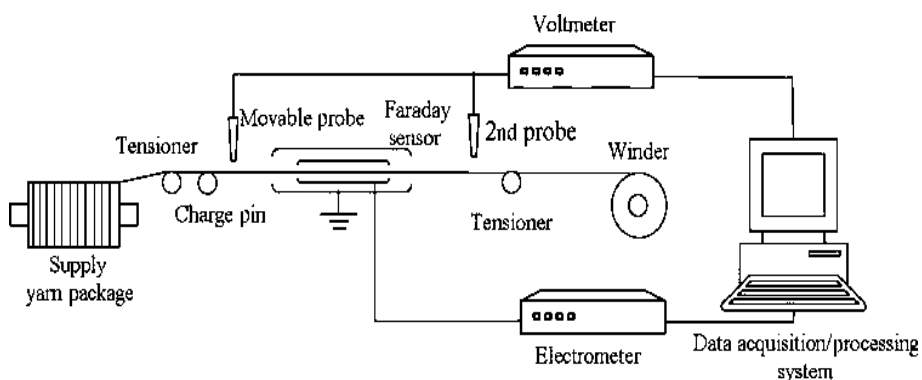


Fig 6 Linear tester instrument for static charges measurements.

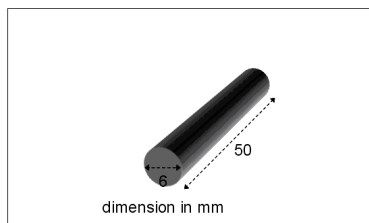


Fig. 7 Stainless Steel Pin

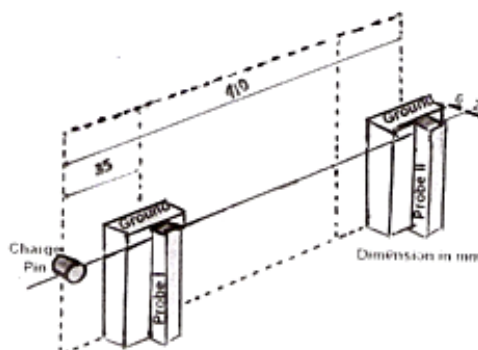


Fig.8 Charge Pin and Probes

Antibacterial Activity

The antibacterial activity of PP/Irguard composite fibers is shown in Table 6 which revealed that the three PP/2% Irguard composite fibers has given after one hour a low reduction growth of *E. coli* and *S. aureus* with the exception of PP/2% Irguard 1000 which has 99% reduction for *S. aureus*. After 24 hrs, the percentage reduction of *E. coli* and *S. aureus* has increased to 99.99% for all samples with the exception of PP/2% Irguard 5000 , which indicates 20% reduction for *E.coli* and 99.4% reduction for *S. aureus*. After 24 hrs, for five washings, the same previous sample gives poor reduction 20% for *E. coli* and *S. aureus*, in comparison to the others which indicate 99.99% reduction of bacteria and with the exception of PP/2% Irguard 7000 which shows 99% reduction for *S. aureus*. The study has revealed that PP/2% Irguard 1000 has excellent antibacterial activity against *E. coli* and *S. aureus* followed by PP/2% 7000 composite fibers.

Table 6 Antibacterial activity of PP/ Irguard composite fibers.

| Sample | Reduction <i>E. coli</i> % | | Reduction <i>S. aureus</i> % | |
|----------------|-------------------------------|-------|---------------------------------|-------|
| | 1hr | 24hr | 1hr | 24hr |
| PP control | 20 | 20 | Nil | Nil |
| PP/2% Irg.1000 | 20 | 99.99 | 99 | 99.99 |
| PP/2% Irg.5000 | 20 | 20 | 20 | 99.4 |
| PP/2% Irg.7000 | 59 | 99.99 | 20 | 99.99 |

Transmission Electron Microscopy (TEM)

TEM micrographs of the produced PP/ 1% Irguard 5000 and 7000 composite fibres were observed in Figs 9, 10 which show that the Irguard particles are well dispersed in the PP matrix and the particles are in the range of 45-62 nm (PP/ Irg.5000) and 154-194 nm (PP/ Irg. 7000) with the appearance of some agglomerations of the Irguard compounds.

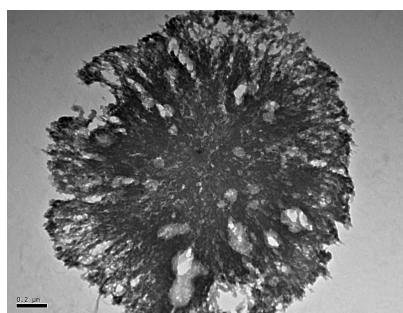
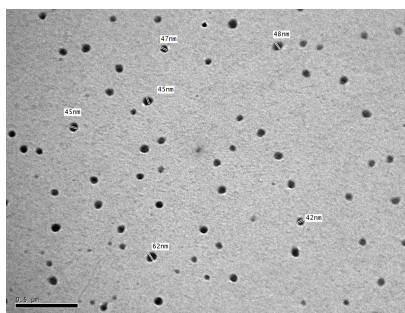


Fig.9 (a) TEM of dispersed PP/ 1% Irguard 5000 (b)TEM of agglomerated PP/1% Irguard 5000

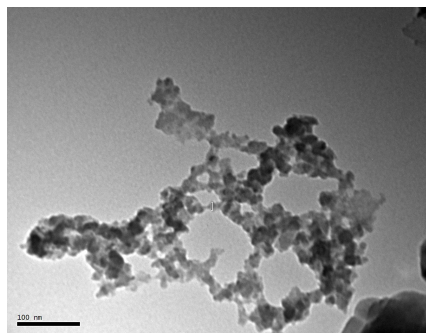
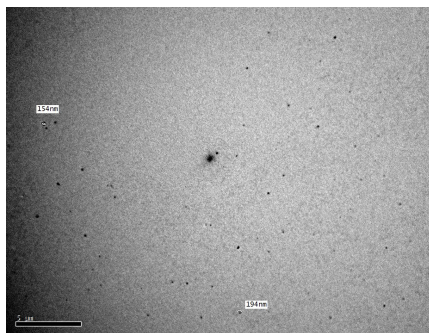


Fig.10(a) TEM of dispersed PP/1% Irguard 7000 (b) TEM of agglomerated PP/1% Irguard7000

Conclusion

The newly produced PP/Irguard composite fibers have greatly improved PP properties. For the mechanical properties of fibers, especially the fiber modulus is increased 26-29% at low concentration addition 0.1-0.3% of the Irguard compounds indicating the creation of strong composite fibers. Increasing the

Irgaguard compounds up to 1% into PP decreases the mechanical properties of fibers. From DSC results, it is observed that the melting temperatures slightly increased, the heats of fusion and the percentage crystallinity are nearly maintained constant upon increasing the concentration of Irgaguard into PP from 0.1-0.3%.

TGA study has revealed that the incorporation of 0.3% Irgaguard 7000 to PP creates more thermally stable fibers than that of PP control , at 450° C (9.45% residual wt) and the thermal stability is more effective in case of the composite fibers PP/0.1% Irgaguard 7000/ 0.1%Zn (17.6% residual wt) . The thermal stability of PP/0.3% Irgaguard 5000 is less than that of PP/ 0.3% Irgaguard 7000. Composite fibers of PP/Irgaguard have proved to have excellent antibacterial activity against E,Coli and S.aureus especially for PP/2% Irgaguard 1000 and PP/2% Irgaguard 7000 The PP Irgaguard fibers proved to have excellent antistatic property especially that of PP/0.1% Irgaguard 1000 and PP/1% Irgaguard 5000, these fibers can be used as nonwoven fabrics for hospital applications such as wound and burn healings .TEM for the composite fibers have shown dispersion of the Irgaguard compounds into PP matrix with the appearance of some agglomerations.

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