Pak. J. Biotechnol. Vol. 16 (2) 81-90 (2019) pISSN: 1812-1837 eISSN 2312-7791 www.pjbt.org
http://doi.org/10.34016/pjbt.2019.16.1.13

ANTISTATIC PACKAGING OF PLASTICIZED BIODEGRADABLE POLYLACTIC ACID / GRAPHENE NANCOMPOSITES

Saif M. Jaseem and Nadia A. Ali

Department of Physics, College of Science, University of Baghdad, Baghdad, Iraq
E. mail: saif.mohammad1990@icloud.com, nadiaabbas78@scbaghdad.edu.iq

Article received 24.3.2019, Revised 11.5.2019, Accepted 20.5.2019

ABSTRACT

Poly lactic acid is inexperienced various to organic compound artifact plastics, employed in packaging with graphene that being one atom thick sheet, composed of sp2 carbon atoms organized in an exceedingly flat honeycomb structure .In this analysis victimization plasticizer thymol with composites were ready by an answer casting technique with (0.5-10) % towers Graphene .Experimental work contain morphological (AFM,FTIR), mechanical(Tensile, Tear, Hardness),electrical conductivity Color , contact angle, and TGA . Results hyperbolic electrical physical phenomenon with hyperbolic Graphene and makes the composite less resistive and appropriate to be used as antistatic packaging , increase the strength and tensile modulus and elongation at (0.5-1)% and attenuate in (3-10%)%,Tear Resistance attenuate once the tensile decrease however hardness hyperbolic with graphene .The results of contact angle of pure PLA is 83◦ that hydrophobic and attenuate to 51◦ at PLA/thymol/Graphene 10% percent to get hydrophilic that able to dissipate or promote the decay of electricity and improve method ability of device. Color and Brightness show that attenuate however appropriate for antistatic packaging and have become opacity at 100 percent Graphene. Thermal stability shows that Graphene hydrolysis by oxidization and exfoliation of carbon and also by the functionalization of sheets graphene to hence on the mass loss of composites.

Key words: Polylactic acid, Graphene, Antistatic packaging, Color, Contact angle

INTRODUCTION

Biopolymers square measure thought-about a property various to oil-based artificial polymers since they're renewable and don't contribute to environmental pollution being perishable and so, they're presently utilized in many applications like packaging and electrical packaging like antistatic packaging (Justine et al., 2017). Poly-lactic acid (PLA) gained a lot of attention thanks to its attention-grabbing properties as well as smart method ability, mechanical properties and performance, creating it an honest candidate for substitution ancient polymers in many applications and moreover, appropriate for mechanical recycling (Bonifacio et al., 2017).

PLA is linear acyclic thermoplastic polyester derived from acid, that's obtained from the fermentation of 100 percent renewable and putrefiable plant sources, like corn or rice starchesand sugar feed stocks. It should be created by chemical conversion of corn or completely different carbohydrate sources into dextrose that followed by polymerization by polycondensation of foodstuff acid monomers or lactide. However, the foremost common because of end up PLA is that the Ring Opening Polymerization of lactide matter intentional from acid, utterly completely different stereochemical forms exist for lactide: either L-, D- or every L, D-Lactide (mesolactide), each one having their own melting properties (Valdez-Garza et al., 2017). PLA could be a hydrophobic biopolymer with contact angle is 81◦C, also Tg of 40-70°C and the strength of PLA is 32–53Mpa (Kanchana et al., 2016).

Graphene consists of monolayer of conjugated sp2 carbon atoms secured into 5-membered rings that unit densely packed into a honeycomb lattice and it is thinnest material discovered inside the planet with one layer thickness to be however one nm, with tremendous application potentials (Peter Quosai et al., 2018, Anstey et al., 2016). These embrace future generations of high speed and radiofrequency logic devices, thermally and electrically conducting reinforced nanocomposites, electronic circuits, sensors, and clear and versatile electrodes for displays and star cells, thermal natural phenomenon and electrical natural phenomenon, attraction interference shielding ability, flexibility, transparency, and low constant of thermal growth (Suliman et al., 2016, Chia et al., 2015). Conductors have surface resistance between $10^4 - 10^6$ Ω/cm and that they discharge quickly. Insulators square measure the supply of electricity and have beyond 10^{12} Ω/cm surface resistance. Between these materials has associate degree electrical phenomenon region and, in these regions, materials have surface résistance between $10^6 - 10^{12}$ Ω/cm that we tend to decision antistatic materials. Static charging is a very important drawback for our daily lives. We've to beat this drawback as a result of it ends up in serious consequences. for example, equipment scan be break down. If there's device, static charge may be any place (Fig. 1) (You et al., 2017, Bauhofer and Kovacs 2009, Zoe et al., 2018).

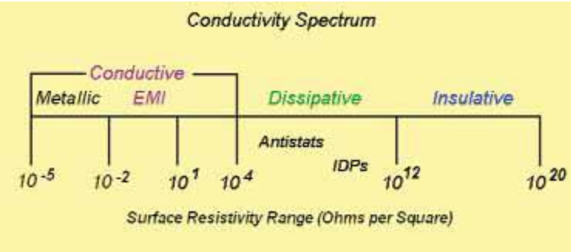


Fig. 1: Surface Resistivity range in Ω.cm of materials (Bauhofer and Kovacs 2009, Zoe et al., 2018).

Graphene/polymer composites will considerably improve durability, coefficient of elasticity, electrical, and thermal properties. Compared with carbon nanotubes, graphene encompasses a higher surface-to-volume quantitative relation as a result of the unavailability of the inner surface of carbon nanotubes to the chemical compound matrix. This makes graphene an additional favorable nanofiller for rising chemical compound properties like poly(methyl methacrylate), poly (vinylalcohol) phenylethylene and PLA, are used as chemical compound matrices for graphene to fabricate graphene/polymer composites with superior mechanical, electrical, and thermal properties (Nan Nan et al., 2015, Liimatainen et al., 2017)

MATERIALA AND METHODS

Materials: Powder PLA that AI type with p= 1.25g/cm3 provided by (Shenzhen Esun Industrial Co. Ltd). Graphene provided from Sigma-Aldrich that particle size is60nm.

Film of PLA/thymol mix was ready with weight of 95/5 (w/w) dissolving in chloroform for 60°C for two hours beneath magnetic stirring unceasingly till the answer was cleared; then solid into Petri dish that a 20cm diameter at temperature for twenty-four hour to make sure complete solvent removal.

Nanocomposites PLA/Thymol/Graphene invented by casting technique solve three weight unit of PLA weight unit of softener thyme camphor in thirty cubic centi-meter of chloroform with continuous stirring for two h to utterly dissolve the PLA mix. Graphene at construction of (0.5, 1,3,5,10) World Trade Center was spread in chloroform (10mL) and PLA–Graphene resolution stirring at three hand casted on Petri dish to dried for 4 h. The dried composite films were in the raw off fastidiously from the Petri dish, films were finally dried in a very vacuum at 40◦C for twelve h. The obtained films were hold on in laboratory at temperature and cut consistent with ASTM for characterizations (Fig. 2).

Fig 2: Samples of test of pure PLA and PLA/thymol /Graphene composites

Characterizations: The surface morphology of graphene nanoparticles was ascertained with AFM micrographs as shown in Fig. 3. It emerges that average diameter 50.22 nm for graphene particles.

Thickness: The thickness calculated for pure PLA and PLA/Thymol mix and PLA/Thymol/ Graphene nano composites by electronic digital micrometer and notice that's 0.110millimeter for all composites.

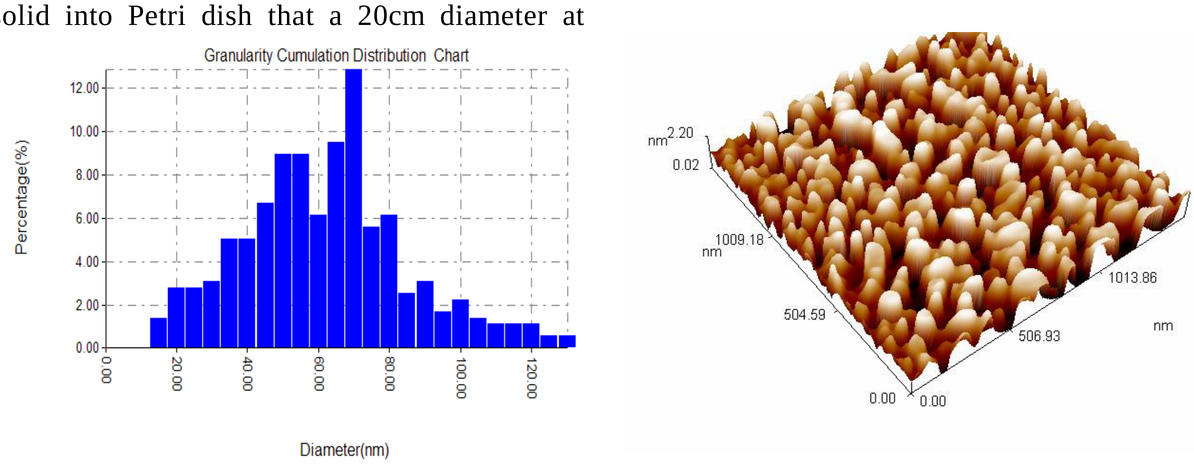


Fig. 3: AFM analysis images of graphene nanoparticles used in the work

Fourier Infrared (FTIR): Analysis was recorded with the assistance of Shimadzu kind FTIR -7600 in wavenumber between 400 to 4000cm^{-1}.

Electrical conductivity: The electrical phenomenon has been measured as a operate of temperature within the vary 30-110◦C by exploitation the electric resistance (ρ) of the films is calculated by exploitation the subsequent equation: $\rho = R.AL$……….(1)

Where: R is that the sample resistance, A is that the cross-section space of the film and L is that the thickness of the samples. The physical phenomenon of the films decided from the relation: $\sigma dc.=1/p$…………(2)

The activation energies can be calculated from the plot of Ln σ versus l000/T from physicist equation to get the energy (Ea) by the subsequent formula: σ=Aexp(-Ea/KBT)………(3) KB is that the constant that is 1.3806 ×10-23 J/K, T is that the temperature in Kelvin (Arijit Basu et al., 2016).

Strength: Test according to ASTM D-882 (2010) measured modulus of snap, strength and elongation equipped with a five-weight unit load cell in tensile mode. strength (σs), Young's modulus (E) were determined per the subsequent equation:σs=F/A…………(4),

E=FL0/AΔL………(5)

Where: F: force exerted on associate degree object below tension, L0: original length, A: cross-section space, ΔL: length of the thing changes.

Tear Strength: decided on an equivalent Universal Electronic measuring instrument per ASTM D-1922 (2014) by the garment tear methodology. The sample size was a hundred-milli -meter long and sixty-three millimeter-wide having a cut of fifty millimeter at the middle of sample.

Hardness: was conducted at temperature (25°C) with 50% humidness. The surface hardness of the samples was measured by employing a (Shore A durometer) per ASTM D 2240 (2010). All the hardness values according area unit obtained from a minimum of 3 check results.

Color check and Brightness: Evaluated measure color coordinates by equipment CIELAB color house L* (lightness), a*(redness – greenness) and b* (yellowness -blueness) were analyzed employing a Konica CM-3600d color. Average values for samples were calculated by the color a distinction (ΔE) was evaluated by equivalent 6 (2006).

$\Delta E=\sqrt{(\Delta a^2+\Delta b^2+\Delta L^2)}$…………………6

Where: ΔL = L stander*-L sample, Δa = a stander*– a sample, Δb = b stander*-b sample, organism values for white paper were L = 96.86, a = - 0.02 and , b = 1.99 severally for pure PLA.

Contact angles: the contact angles (CA) were measured by ASTM D7334 (2013), the sessile drop technique employing a contact angle system (OCA20, Data physics, Germany) at temperature. The testing used water measured during a direction finder through drop form analysis. The contact associate degreeless of water was measured (right and left contact angles) on a flat sample surface at an interval of 60s.

RESULTS AND DISCUSSION

In Fig. 4 Shows the all main peaks of pure PLA that realize in 1418, 2994 and 3600cm^{-1} were allotted to the C–O, C–H (double), the bond O–H stretching of the –CH(CH3)–OH finish cluster of PLA, severally. PLA the height at 3000-2850cm^{-1} were allotted to the –C–H uneven and trigonal vibration of CH3 teams within the facet chains, peak at 3424 cm−1 of -OH, the height at 2921cm^{-1} uneven stretching –CH2-, peak at 1730cm^{-1} like the stretching vibration radical (C-O) from the perennial organic compound units (is because of the radical within the dairy product acid), peaks at 1300-1500cm^{-1} of the modification vibrations of methyl radical of PLA area unit seem at peal at 1414cm^{-1} of –CH_3 bending vibration and peak at 1150 cm^{-1} of –C–O– stretching vibration from the organic compound units, and peak at 934 – 851cm^{-1} of C-C single. In PLA/Thymol/G.O composites shows the peak at 3404cm−1 belong to the O–H stretching, peak at 1517cm^{-1} corresponds to the stretching vibration peak of C=O in the ester bond and carboxylic groups that connected with graphene chains onto the surface of GO. The peak at 1645cm^{-1} is most possibly due to the skeletal vibration of graphitic domains. Furthermore, the characteristic peaks of PLA, including the stretching vibration of C–CH_3, the bending vibration of –CH_3, and the asymmetric bending vibration of –O-H), appeared at 995cm^{-1}. The absorbance bands at about 2925cm^{-1} and 2855cm^{-1} in curve are ascribed to hydroxyl groups O-H.

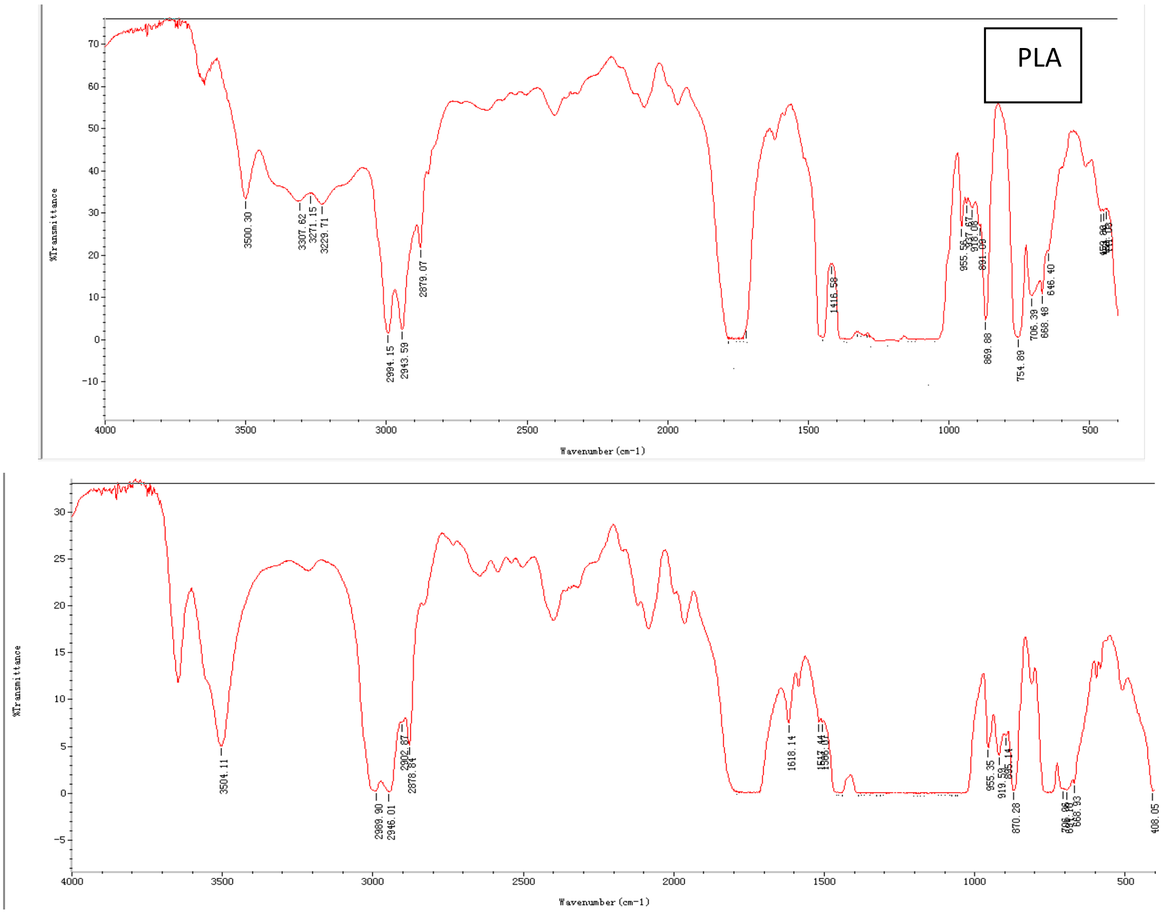
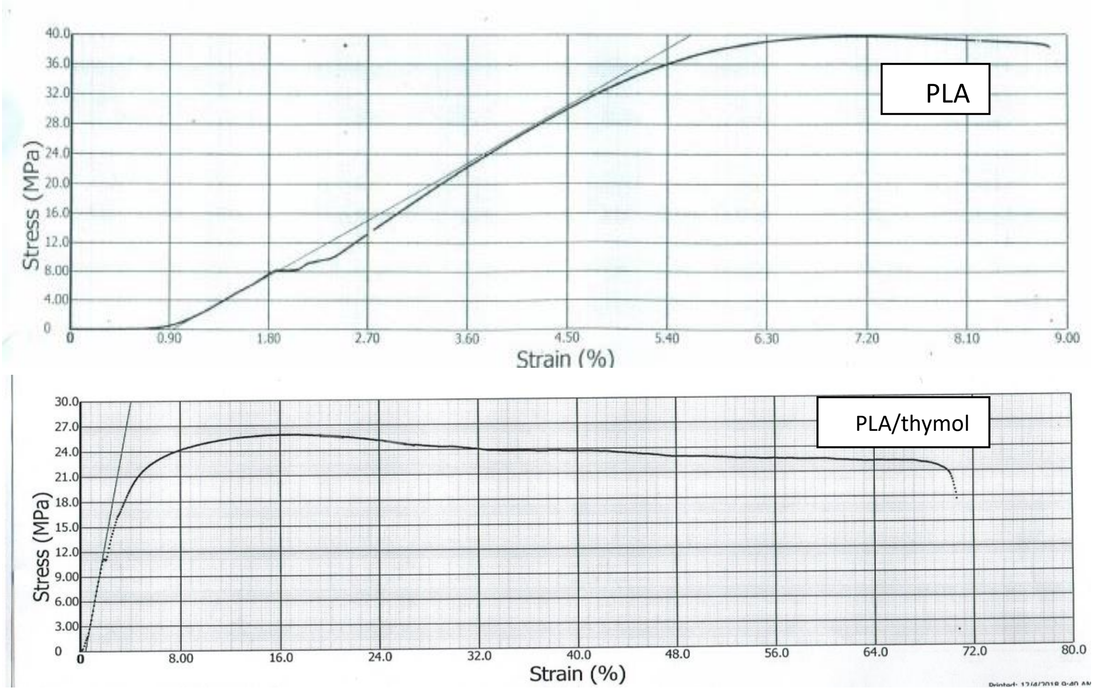


Fig. 4: FTIR of pure PLA and PLA/thymol /Graphene nanocomposites

Mechanical Properties: The pressure strain conduct of the various examples is appeared in Fig. 5 demonstrates the estimations of pure PLA that ductile strength 36 MPa, Elongation 8.5% and Young Modulus a pair of.83GPa in lightweight of the very fact that that PLA based mostly materials are inflexible and weak compound at temperature (RT) due to its Tg~55°C (Anstey et al., 2016).



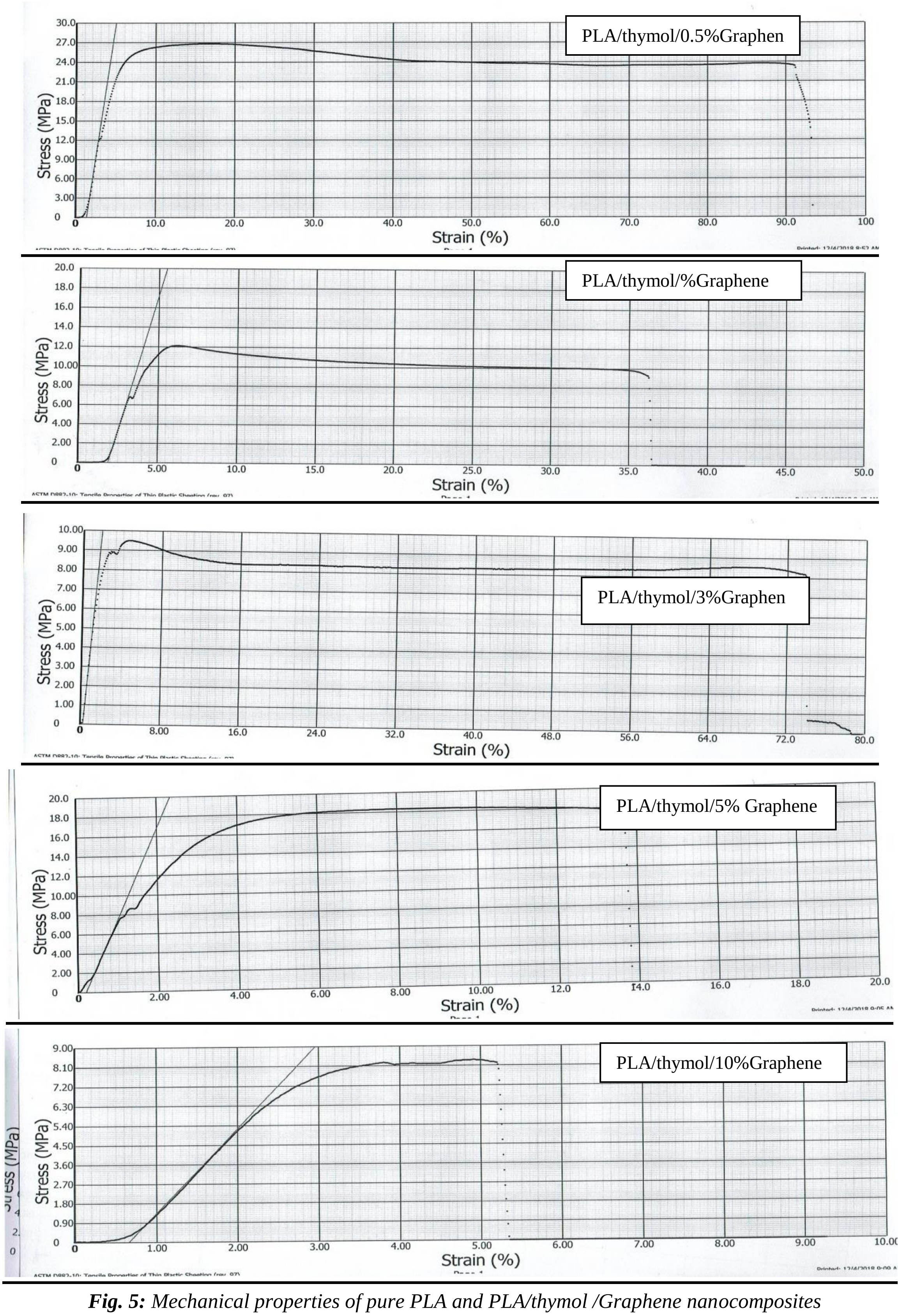


Fig. 5: *Mechanical properties of pure PLA and PLA/thymol /Graphene nanocomposites*

The movies application for antistatic bundling needed adequate ability to abstain from breaking amid the bundling system that mean want materials have high ability, the target of blending with phenol with PLA was to upgrade plastic extension and reduce weakness of PLA. Plasticizer growth into PLA network was to diminish rigid nature of PLA Associate in increment plasticity of PLA on the grounds that capable phenol builds the capability of PLA to plastic distortion that is mirrored within the decline of yield pressure and an growth of twenty-two protraction that show up in Fig (5) that decline in Tensile Strength 36.43 to 24.12MPa, Young modulus from 2.83 to 2.02GPa but improved and swollen in stretching between 8.5-72% at break of PLA film when mixture with thymol.

From 1-5wt is clearly decline within the rigidity and extension is watched for the PLA composites but stay useful in antistatic application since that flexibility of PLA is viably improved with the fuse of Graphene on the grounds that as a scaffold to put off the crack procedure of PLA composites and on these lines decreases the surprising danger of disappointment. At more loadings of Graphene (10wt %) physical property and diminished at 8MPa, five-hitter and progressed toward changing into modification fragile which since growth of 1-5 World Trade Center of graphene basically diminishes the tractable modulus, and consequently the firmness. this is often be} due to the method that graphene can connect when the rotating unreeling by means that of direct contacts or crossover by compound chains, Associate in Nur singed assemble an example spreading over filler organize, that offers ascend to the versatile reaction as depicted in Fig 5 due to the high surface zone of graphene within the nanocomposites, the connected pressure was needed to exchange viably from the grid to graphene layers conveyance concerning upgrade of mechanical properties.

Table 1 demonstrates the estimations of tear engendering check reenacts a previous tear within the film. All plastic sheet with a property of fragility can have exceptionally low tear protection from power and for certain understood that weak materials assimilate lesser vitality to crack than the pliant materials, this is often clearly recorded in Table 1, pure PLA could be a fragile material it demonstrates tear obstruction is 12.5mN/mm because it clearly growth of phenol and Graphene nanocomposites improvement in tear opposition for 0.5-3% between 15.50-14.60mN/mm considerably by the fuse of the Graphene particles that on the grounds that the surface zone of Graphene and contain layers of carbon will hinder or if nothing else to hinder break unfold by digressing their tear approach and at (5-10) twin towers demonstrate the estimations of tear obstruction decline since that composites is progressed toward changing into modification weak that show up in Table 1.

Table 1: *Mechanical properties of pure PLA, PLA/thymol and PLA/thymol /Graphene nanocomposites*

Samples	**Young Modulus GPa**	**Tear Resistance mN/mm**	**Hardness Shore A**
Pure PLA	2.83	12.5	97.66
PLA/Thymol 95/5 %	2.02	13.4	97.60
PLA/Thymol/0.5%Graphene	1.87	15.50	97.50
PLA/Thymol/1% Graphene	1.55	14.90	96.50
PLA/Thymol/ 3% Graphene	1.10	14.60	96.80
PLA/Thymol/5% Graphene	0.26	13.20	97.70
PLA/Thymol/10% Graphene	0.12	11.01	98.20

The estimations of hardness determined by Shore A that proportion of the opposition of a fabric to entrance of a spring stacked needle-like indenter bury the composites, pure PLA is ninety-seven. 66 and decreasing to ninety seven. 60 once utilized plasticizers phenol on the grounds that appear increasingly pliable plastic but motivations lost quality and distended to 98.20 for 5-10 twin towers

Electrical Conductivity: Plastics materials possible to accumulate electricity as a result of their high electric insulation and may be accustomed produce materials with stable static charges like the electrets employed in perishable filtration materials. The surface electrical resistance is inside the vary (10^{10}-$10^{12}\Omega$/cm) for associate antistatic film (Zoe et al., 2018)

The electrical conduction of the pure PLA is showed in Fig. 6 and also the conduction is 1.39E-12 S/cm as a result of PLA is characterized by a high electrical resistance and stuff materials, an inclination toward electricity additionally at PLA/Thymol keep dielectric and also the conduction is 1.49E-12 S/cm.

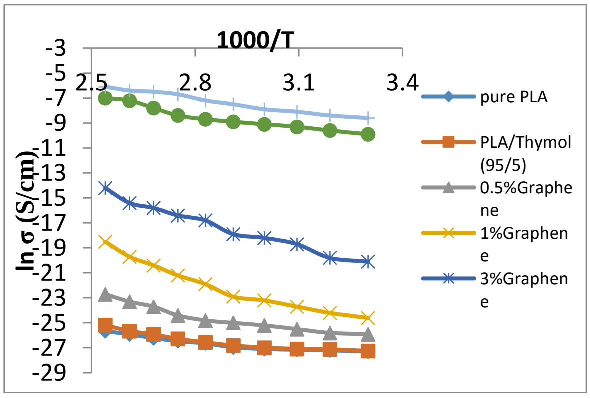


Fig. 6: *Electrical conductivity of pure PLA and PLA/thymol/Graphene nanocomposites*

The electrical conduction of the composites PLA/thymol/Graphene distended with increasing in grouping of Graphene that due to a solitary nuclear layer of carbon which mineral that is associate chemical element of carbon that's comprised of all told respects firmly fortified carbon molecules sorted out into a polygonal shape cross section, that produces graphene therefore extraordinary is its sp2 interbreeding and intensely slim nuclear thickness (o.345nm). Carbon molecules have associate combination of half-dozen electrons; a pair of within the internal shell and four within the external shell. The four external shell electrons in a private carbon molecule are accessible for compound holding, nevertheless in graphene, each to is related to three different carbon iotas on the 2D plane, outgoing one negatron uninhibitedly accessible within the third measure for electronic physical phenomenon. These exceptionally moveable electrons referred to as pi (π) electrons and placed on top of and beneath the graphene sheet. These pi orbitals cowl and facilitate to boost the carbon to carbon bonds in graphene. On a really basic level, the electronic properties of graphene are managed by the holding and hostile to holding (the cornice and physical phenomenon groups) of those pi orbitals that prompted increment the electrical conduction between (5.43 E-12 S/cm to a pair of.83E-4 S/cm) at temperature show up in Table 2.

Table 2: *Table 2: Electrical conductivity values of pure PLA and PLA/thymol/Graphene nanocomposites.*

Samples	***Electrical conductivity at (R.T) (S/cm)***
Pure PLA	1.39E-12
PLA/Thymol 95/5 %	1.46 E-12
PLA/Thymol/0.5% Graphene	5.43E-12
PLA/Thymol/1% Graphene	7.53E-11
PLA/Thymol/ 3% Graphene	1.38E-8
PLA/Thymol/5% Graphene	6.64E-5
PLA/Thymol/10% Graphene	2.83E-4

Contact Angle: In antistatic packaging need to prevent the build-up of static electrical charge due to the transfer of electrons to the material surface. Electrostatic charging of composites can lead dust deposition, electric shocks and damages in electronic equipment therefore antistatic packaging able to dissipate or promote the decay of static electricity. Poly lactic acid a biomaterial that have combination of biocompatible, biodegradable and have relative hydrophobic surfaces with approximate 83˚ from Fig. 7 high static electricity and low moisture regain that are attributed to the hydrophobic nature of synthetic. PLA can cause a sense of discomfort, creating electric shock and attracting dust and soils in a dry environment therefore used materials and filler to reduce the hydrophobic surface and increased the hydrophilic surface.

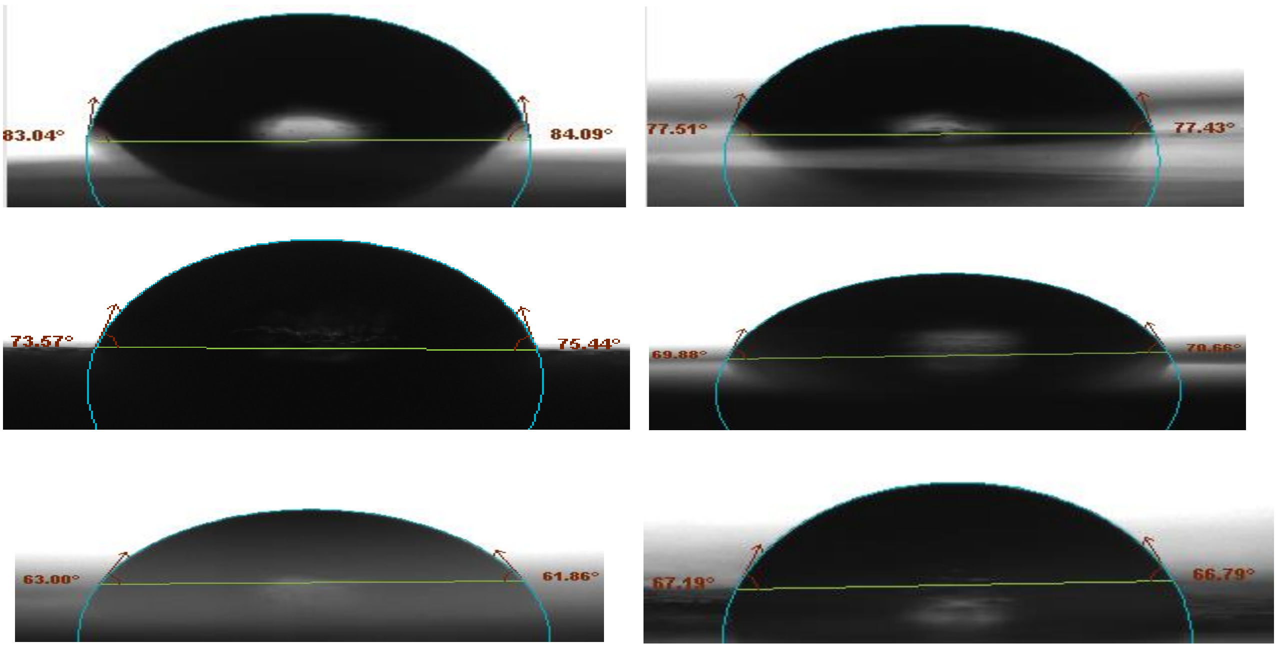


Fig. 7: Contact angle of pure PLA and PLA/Thymol/Graphene composites

The wettability of pure PLA and PLA/Thymol/Graphene nanocomposites with different is shown in Fig 7. The water contact angle decreased from 80°-51° with the addition of thymol and Graphene this was due to the hydrophilicity of thymol and the amount of hydroxyl hydrophilic that containing functional groups on the Graphene surface can easily adsorb water from air thus increasing the composite absorption capacity of water and increases its hydrophilicity. Polar functional groups that appear in FTIR shown in Fig. 4 of composites can form and enhance bond ability include (C=O), (HOOC), (HOO-) and (HO-) groups that appear into polymers can be highly beneficial to improving the surface characteristics and wettability and contact angle .

Color and brightness: PLA are very straight forward and drab in the noticeable area of the spectra (400–700 nm) that have straightforward is 90.05% and 88.87 of PLA/thymol show up in Table 3.

Table 3: *Color Properties of pure PLA and PLA/thymol/Graphene composites*

Sample	L*	Brightness %
Pure PLA	90.05	80.88
PLA/thymol (95/5)	89.87	88.47
PLA/thymol/0.5%Graphene	83.10	79.30
PLA/thymol /1% Graphene	75.70	73.20
PLA/thymol/3% Graphene	66.04	62.24
PLA/thymol/5% Graphene	59.50	55.41
PLA/thymol /10% Graphene	-20.75	-52.30

Splendor is rate reflectance of light at wavelength 457 nm demonstrate that high brilliance in unadulterated PLA that is 80.88% and 88.47% for PLA/thymol, that due to the free volume of the polymer organize, as clarified somewhere else, in this way expanding the portability of the polymer chains and diminishing the darkness and expanded straight forward and splendor by allowing a superior entrance of the light additionally that thymol was drab semi-straight forward precious stones expanded in straightforward and splendor the distinctions among tests were not detectable to the human eyes.

Table 3 shown Color parameter of unadulterated PLA and PLA/thymol/Graphene composites diminished in L* (Transparency) between in (83.10-59.50) and brilliance in 79.30-55.41% in light of the fact that Graphene is comprised of nebulous carbon structures and turbo-stratically stacked graphene sheets and the utilization of most extreme measures of biochar produces a slight variety and the film become haziness and give dark shading to film. In the advancement of biodegradable PLA-based antistatic bundling nanocomposite application with limiting the decrease of optical straight forwardness, which by and large begins from light dispersing brought about by nanofillers disseminated inside the film.

Thermal Properties: Thermal stability is key factor used to evaluate the application field of materials. Thus, the thermal stability of polymer and composites need to be investigated to meet application requirements. The thermogravimetric analysis showed that the decomposition temperatures of pure PLA Fig. 8 mass loss are lower occurred in the 387.89℃ this significant decrease in thermal stability for PLA. The thermal stability of the PLA/Thymol/Graphene nano-composites were decomposing at temperatures with the maximum decomposition occurring at approximately 392.81°C and 405.72◦C. This indicates that the dispersed graphene-based fillers in the PLA matrix have a slight influence on the thermal stability of their nano hybrids by oxidation and exfoliation of graphite or the functionalization of graphene sheets give rise to marked differences in the mass loss % as a function of increasing temperature ◦C with constant heating rate.

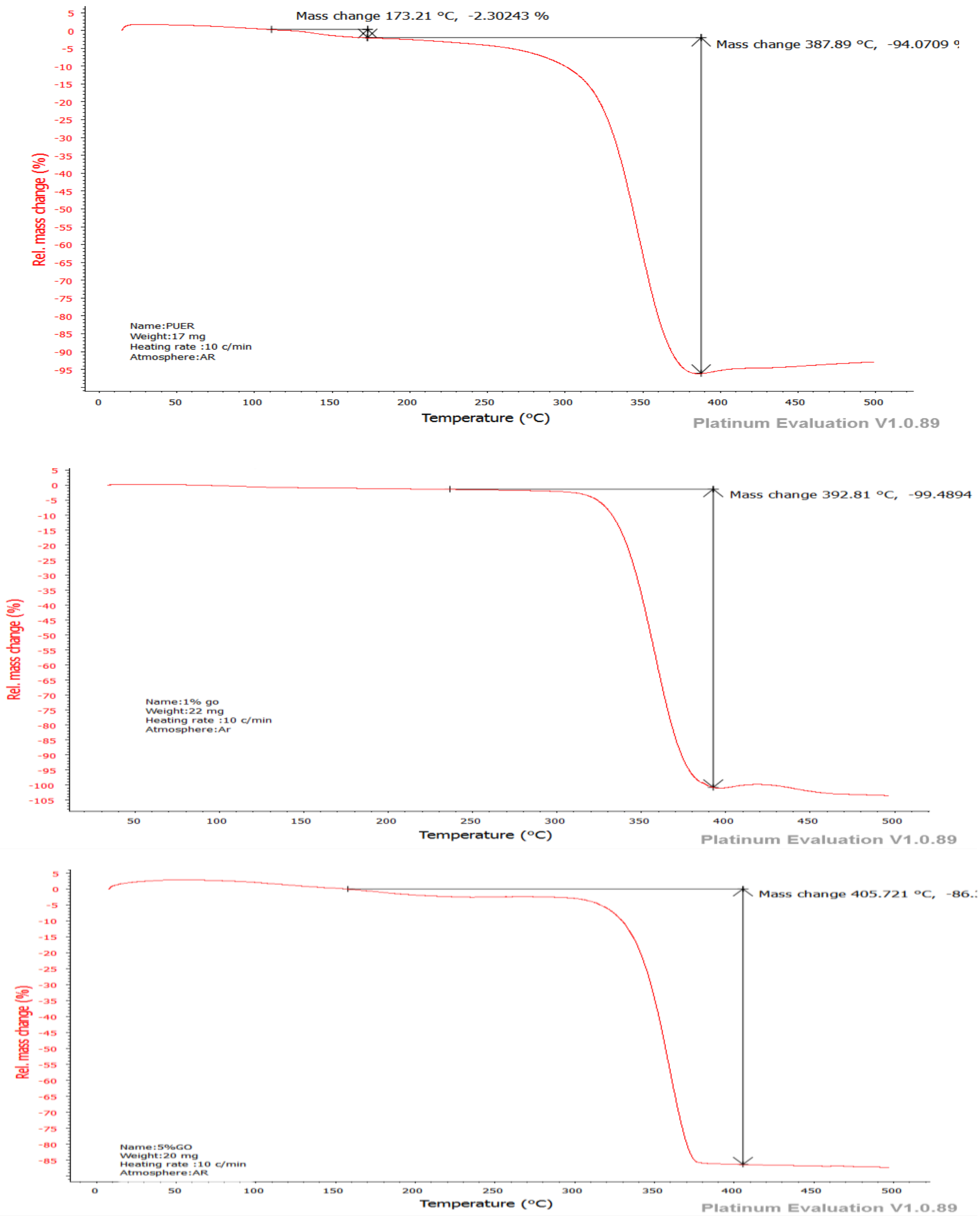


Fig. 8: Thermal gravimetric analysis of pure PLA and PLA/Thymol/Graphene composites

Conclusion

PLA/Thymol/Graphene composites were created by an answer throwing strategy. The sheet of graphite of carbon significantly affects its properties i.e., the electronic, mechanical, contact edge, shading test and warm solidness. In this investigation demonstrate that electrical conductivity increment with expanded Graphene and makes the composite less resistive and appropriate for use as antistatic bundling for the transportation and capacity of electronic segments, brought about mechanical test demonstrate that expanded the Tensile quality and Young Modules yet diminished in lengthening and Tear Resistance and expanded in hardness. Contact edge diminished when utilized plasticizers and Graphene because ended up hydrophilic surface that helpful in antistatic bundling to scatter a static charge. Shading and Brightness demonstrate the straightforwardness of the unadulterated PLA film was high that 90% whiteness (L*) and diminished however stay satisfactory until 5% and progressed toward becoming haziness at 10% biochar. Warm dependability demonstrate that include graphene expanded the solidness of unadulterated polylactic corrosive by oxidation and peeling of graphite or the functionalization of graphene sheets offer ascent to checked contrasts in the mass misfortune.

REFERENCES

Anstey A., Vivekanandhan S., Rodriguez-Uribe A., Misra M. and A.K. Mohanty, Oxidative acid treatment and characterization of new biocarbon from sustainable miscanthus biomass. Sci. Total Environ. 550: 241-247 (2016).

Arijit Basu, Michael Nazarkovsky, Rohan Ghadi, Wahid Khan, Abraham J. Domb, Poly-(lactic acid)-based nanocomposites, Polym. Adv. Technol. 28: 8 (2016).

ASTM D1746, Standard Test Method for Transparency of Plastic Sheeting, covers instrumental measurement of regular transmittance of clear and colorless thin sheeting (2006).

ASTM D1938, ASTM D2240-15E1, ASTM D73-34 -08, ASTM D882, Standard Test Method for Tensile Properties of Thin Plastic Sheeting Volume 08. 01 (2010)

Bauhofer, W. and J.Z. Kovacs, A review and analysis of electrical percolation in carbon nanotube polymer composites. Compos. Sci. Technol. 69: 1486-1498 (2009).

Bonifacio, M.A., Cometa, S., Dicarlo, M., Baruzzi, F., de Candia, S., Gloria, A. and E. De Giglio, Gallium-modified chitosan/Poly-(acrylic acid) bilayer coatings for improved titanium implant performances. Carbohydr. Polym. 166: 348-357 (2017).

Chia C.H., Downie A. and P. Munroe, In Biochar for environmental management (eds Lehmann J., Joseph S.), 2nd Ed. New York, NY, Taylor and Francis Pp. 89-109 (2015).

Justine Muller, Chelo González-Martínez and Amparo Chiralt, Combination of poly(lactic) acid and starch for biodegradable food packaging. Materials 10: 952 (2017).

Kanchana Boonruang, Wannee Chinsirikul, Bongkot Hararak, Noppadon Kerddonfag, D. and Vanee Chonhenchob, Antifungal poly-(lactic acid) films containing thymol and carvone. MATEC Web of Conferences 67: 06107 (2016).

Liimatainen, V. et al., Mapping microscale wetting variations on biological and synthetic water-repellent surfaces. Nat. Commun. 8: 1798 (2017).

Nan Nan, David Devallance, Xinfeng Xie and Jingxin Wang, The effect of bio-carbon addition on the electrical, mechanical, and thermal properties of polyvinyl alcohol/biochar composites. Journal of Composite Materials 50: 9 (2015).

Peter Quosai, Andrew Anstey, Amar K. Mohanty, and Manjusri Misra, Characterization of biocarbon generated by high- and low-temperature pyrolysis of soy hulls and coffee chaff: for polymer composite applications. R. Soc. Open. Sci. 5:8 (2018).

Standard Practice for Sur-face Wettability of Coatings, Substrates and Pigments (2013).

Standard Test Method for Rubber Property-Durometer Hardness (2010).

Standard Test Method for Tear-Propagation Resistance (Trouser Tear) of Plastic Film and Thin Sheeting by a Single-Tear Method (2014)

Suliman W., Harsh J.B., Abu-Lail N.I., Fortuna A.M., Dallmeyer I. and M. Garcia-Perez, Influence of feedstock source and pyrolysis temperature on biochar bulk and surface properties. Biomass Bioenergy 84: 37-48 (2016).

Valdez-Garza, J., Avila-Orta, C., Cruz-Delgado, V., Gonzalez-Morones, P., Hurtado-Lopez, G., Waldo-Mendoza, M., Quinones-Jurado, Z. and J. Perez-Medina, Antistatic films based on polymer nanocomposites. Boletín del Grupo Español del Carbón 44: 8-9(2017).

You, F., Li, X., Zhang, L., Wang, D., Shi, C. and Z. Dang, Polypropylene/poly-(methyl methacrylate)/graphene composites with high electrical resistivity anisotropy via sequential biaxial stretching. RSC Adv. 7: 6170–6178 (2017).

Zoe Vineth Quiñones-Jurado, Miguel Ángel Waldo-Mendoza, José Manuel Mata-Padilla, PabloGonzález-Morones, JuanGuillermo Martínez-Colunga, Florentino Soriano-Corral, Víctor Javier Cruz-Delgado, Ronald Francis Ziolo and Carlos Alberto Avila-Orta, Transparent low electrostatic charge films based on carbon nanotubes and polypropylene. Homopolymer Cast Films. Polymers 10: 55 (2018).