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A Comparative Analysis on PLA Based Aluminium Foils for Food Package

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Nano aluminium based PLA composites for foil preparations is one of the better choices for food packaging on basis of biodegradability after usage. Present scenarios focused on the biodegradability of packing base due to micronize pollution effect in the environment. Present research focuses on structural thermal degradable properties of PLA base aluminum foils with experimentation and computational simulation using Ansys. The work carried out using Al2O3 nano, aluminium, natural biodegradable with PLA, after the experimentation best results got for 60 µm thickness of foil in all the experiments. The further work carried out by doing computational structural analysis to compare foil strength at different temperature conditions for further validation of results thermal stability of the foil compared both experimentally and with Ansys work bench. Present work concludes a novel phenomenon in foil preparation to increase biodegradability up to 10 percentage when compared with regular aluminum foils.
Keywords: PLA, Al2O3, Nano foils, Bio-degradation,Thermal Stability.

1. Introduction

A huge volume of produced plastics have been using in the packaging industry since the last decade of the 20th century. The usage of plastics materials is comparatively cheaper than the other material used in packaging industry. when compare to other materials in the packaging industry plastic material reduces the cost of packaging while meeting convenience, softness, good aesthetic qualities, lightness, and transparency. Recently, 41% of such plastics have been consumed in packaging applications among which 47% are being used for packaging foodstuffs.These plastics are usually fabricated from polyolefins such as: Polypropylene (PP), Polystyrene (PS), Polyethylene terephthalate (PET) and Polyethylene (PE) that are fully petrochemical-based materials. PP can be used for hot-fill liquids due to its high distortion temperature. Nano materials have the potential to revolutionize the food industry. The commodity goods we use today consist of innumerable plastic-based tools. However, the overuse of plastics has its environmental cost. Degradable Environment- friendly PLA plastic is by far the best sustainable we have. Developing smart packaging to optimize product shelf life using nanotechnologies has been the goal of many companies.consequentially, it has been proposed as a renewable and degradable plastic for use in service ware, grocery bags, waste-composting bags, films, and controlled release materials for pesticides and herbicides.

Although these features make PLA an appropriate candidate for food packaging there are, however, some important issues that should be overcome such as poor thermal stability, low mechanical resistance, and limited gas barrier properties. The food market demands technologies, which are essential to keep market leadership in the food processing industry to produce fresh authentic, convenient and flavorful food products. Prolonging the product shelf life and freshness as well as improving the quality of food are the target. Developing smart packaging to optimize product shelf life using nanotechnologies has been the goal of many companies. This purpose needs materials with low cost synthesis with conventional and NANO combinations well known as NANO composites. Present work focuses on development and evaluation of properties of different NANO composites.

1.1 Research objective: The technical parameters have to observe for more clarification on usage of NANO materials in films. In the future, the use of green composites to improve the dispersion and interfacial adhesion of PLA and carbon Nano materials would further enhance their performance. The development of an advanced single suitable and effective method to incorporate CNMs into PLA without losing the CNMs dispersed state (as in solution casting) is essential. By taking the advantage of PLA mixed with Nano's a biodegradable food based packaging foils should develop with high strength is one of the enhanced research area can be focused. In any case, there has been consistently expanding exertion in the advancement of various types of packing materials so as to upgrade their adequacy in keeping the nourishment quality with improved properties can be prepared. As a part of research biodegradable short fibers should be processed for packaging applications, even though fibers can be used for packaging applications a limited amount of PLA and Nano aluminum with base alumium posses strength to the packaging foils Food applications needed more tests for packing foils investigations need to improve in all types of properties such as mechanical, thermal and chemical.

2. State of art and methods

Compression molding is often applied to incorporate many cellulose nanomaterials, viz., up to more than 70 wt % . Several studies, based on the preparation of PLA/CNM nano composites, have been reported in the literature[1] . In most cases, the cellulose nanomaterials are first dried to form a thin paper film, followed by the inclusion of PLA and then compressed at a given pressure and temperature. In other studies, the cellulose nanomaterials are mixed with PLA to obtain homogenous mixtures, followed by the extraction of the solvent and then compression to form sheets . Among these studies, Robles et al. prepared self-bonded composite made of cellulose nanofibers (CNF) and PLA microfibrils, through melt compression molding. The authors mixed 3 wt% CNF suspension with PLA fibrils (PLAF) by using homogenizer, followed by sonication to enhance the interaction between the two. The mixture was then filtered to extract water and hot pressed with hydraulic press at 110^0C, while the pressing cycle was performed as follows: 20 bar for 10 min after closing the press plates, 30 bar for 1 min and then a curing step at a pressure of 150 bar for 5 min[2]. Nanocomposites concept has technologically introduced novelty in fabrication of a new class of innovative polymeric materials. These have facilitated the fabrication of varieties of polymeric nanocomposites possessing versatile, interesting, and superior properties including barrier, mechanical, electrical, and thermal properties[3]. Additionally, some of these materials have attained fire inhibition, thermomechanical attributes, and heat deflection while maintaining varying polymer matrix transparency. These materials have also demonstrated capability of competing, relative to costing and efficiency in various applications especially in packaging[4]. With regard to the great future prospects of PNC packaging materials, this is favorably anticipated especially relative to the replacement of simple packaging systems with high-tech intelligent packaging systems. The use of biopolymers as packaging films in the food sector has incurred challenges due to their high cost and inferior performances when compared with synthetic polymeric materials[5]. Great potentials abound for growth in the applications of nano-composites in biodegradable and edible packaging films. However, varying NPs have included active and smart prospects in food packaging materials, such as antimicrobial and oxygen-scavenging abilities, enzyme immobilization, and exposure to some degradative factors[6].

3. Experimentation and processing

Since PLA's raw materials are based on agricultural raw materials, the continuous supply of PLA resins is of great significance to the development of the global agricultural economy. The increase in the high molecular weight of polylactic acid is the driving force for the extended application of PLA[7]. Low viscosity multi-purpose epoxy resin specific gravity of 1.14 at room temperature, under the trade name of Bondtite PL-411 and the amine based hardener of specific gravity 0.98 of grade PH-861[8].For the hybrid composites; a constant amount of 2 wt% alumina particles were added to the fiber-matrix mixture. The parametric optimization of present research carried out with Taguchi [9]method of pridiction.

3.1 Materials

The followin materials used to prepare the rolled aluminium nano foils mixed with PLA.

1. Nano alumina, 2.PLA 411 Grade, 3. Pulp preparation With natural fiber

3.1.1 sample preparation: The PLA with inclusion of Storch mixture was pre-heated using a heating plate up to 50 degree Centigrade. The alumina nano particles and chopped glass/carbon fibers of length 1-7 mm (termed as short fibers) with the variation of 1, 2, 3, 4, and 5 wt% was considered for the open casting process. The respective particles and fibers were added separately into the resin in a 100 ml beaker with the aid of a mechanical stirrer running at 100 rpm for 4 h. To reduce the particle agglomeration by shear mixing process, the mixture was further homogenized at a relatively high stirring speed of 500 rpm for 30 min. For the hybrid composites; a constant amount of 2 wt% alumina particles were added to the PLA-matrix mixture. After being sealed in a glass beaker, it was transferred to bath ultrasonically (22 kHz in frequency, 55 % power intensity with a sweep mode) followed by probe ultrasonication for 30 min to achieve the fine particle or fiber dispersion and degassed for 4 h at 75degree Centigrade.

Figure1: Biodegradable foils preparation

The sample preparation process after mould pouring to compression rolling to get different thickness samples@ 30, 50,60,80 and 100 microns as shown in figure1.

Figure 2: Foils with different thickness

3.2 Optimization with Taguchi L9 design

S.No	Parameter 1	Parameter 2	Parameter3	PLA%	Nano%	Thickness(µm)
1	1	1	1	6	1	30
2	1	2	2	6	2	50
3	1	3	3	6	3	60
4	2	1	2	8	1	50
5	2	2	3	8	2	60
6	2	3	1	8	3	30

7	3	1	3	10	1	60
8	3	2	1	10	2	30
9	3	3	2	10	3	50

The ASTM D6110-10 method was followed to prepare the test specimens for the impact energy test. Charpy test rig used for the investigations performed on an impact tester (CEAST) with pendulum energy of 11 J and a span of 60.0 mm. The tests will be conducted at room temperature and normal atmospheric condition with the impact speed of the striking hammer was 3.46 m/s. Similarly, the defects free rectangular test coupons (ASTM D790-10), from each category, were tested for the measurement of flexural properties by using a three-point bending mode. The rig was mounted on an Zwick//Roell Z010 series universal testing machine at a crosshead speed of 1.27 mm/min at room temperature[10]. The span-to-depth ratio of 64 was maintained in order to ensure that the specimens failed due to flexural loading against the shear failure for small span-to-depth ratios. A minimum of five samples of each category was used for all the tests and the average value was considered for the analysis. Surface morphology and the failure mechanism of fractured samples were examined at nano range through the high resolution scanning electron microscopy (HRSEM) equipment Zeiss (EVO MA 15), Germany, with the maximum vacuum capacity of 8.5×10-5 Torr. This equipment was capable of producing a magnification of 50,000× at 20 kV. The voltage of 10 kV was maintained during the SEM operation[11]. The Vaiseshika inverted metallurgical optical microscope7001 IMS, India, with magnifying capacity of 25× to 1200× was used to capture the images under reflection mode.

4. Results and discussions

Food packs must also be easy to handle, be used to dispense the food, and have many other attributes linked to the physical characteristics of the packaging material. Also, in this study presented novel and efficient polymer materials for food packaging based on nanotechnology.The following results obtain after experimentation, SEM, conductivity, stability, hardness, surface finish for optimization.

S.NO	P1 (µm)	P2 (PLA %)	P3 (Nano alumina)	Surface finish(Ra)	Tensile strength (MPa)	Hardness (HV)	Thermal Conductivity (W/mK)
1	30	6	1	5.3	20.8	6.1	2.18
2	30	8	2	6.1	23.2	7.7	2.4
3	30	10	3	5.8	22.4	6.3	2.32
4	50	6	2	6.2	26.3	7.8	2.31
5	50	8	3	7.2	28.1	9.3	2.16
6	50	10	1	6.4	22.1	7.4	2.28
7	60	6	3	6.6	29.8	8.5	2.3
8	60	8	1	6.4	26.4	8.1	2.23
9	60	10	2	8.3	30.61	10.15	2.11

Taguchi predictive analysis

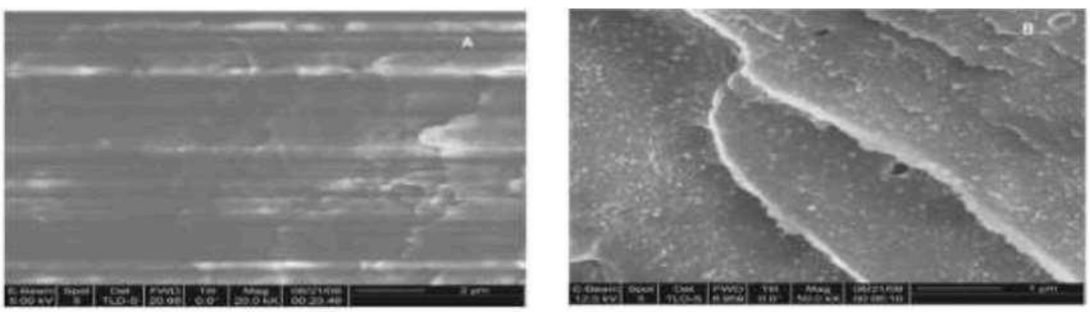
S.NO	S/N Ratio	Mean	StDev	Ln(StDev)	Rank	Thickness	Percent
1	16.1482	10.0585	8.45890	2.14289	9	30µm	6+1
2	18.2308	12.5541	9.67681	2.27219	6	30µm	8+2
3	17.6781	11.9541	9.47919	2.24209	7	30µm	10+3
4	18.8060	13.8874	11.2077	2.41019	4	50µm	6+2
5	19.1954	14.1919	11.2401	2.41952	3	50µm	8+3

6	18.3150	12.1874	9.02202	2.20035	8	50μm	10+1
7	19.0312	15.1874	13.1132	2.58250	1	60μm	6%+3
8	19.0929	14.0874	11.1251	2.40276	5	60μm	8+1
9	19.0312	15.1874	13.1132	2.58250	2	60μm	10%+2

Discussion after optimization:

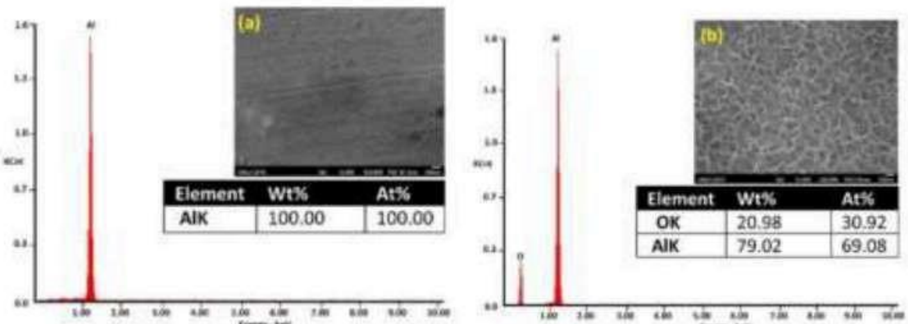
- 1% addition of nano particles not effecting much on output parameters,3% addition of Nano particle is good at 8% PLA and 10% PLA.
- A minimum of 2% Nano addition is appreciable for 6% pla as initial mixing.
- Increment of Nano addition is directly proportional to PLA content.
- More addition of Nano is good for lower thickness with less PLA.
- Not much variation found with 6+3 and 10+2 percentage addition for 60 micron foils.
- For lower thickness foils a minimum of 8% PLA and 2% of Nano is appreciable.

Micro structures for PLA mixed Foil:



Good compatibility between filler and polymer is essential, thus the importance of chemically modified clay. With respect to processing, although exfoliation is recognized as a processing goal, an orderly array of platelets in the polymer matrix, which would maximize effectiveness.

XRD- EDS peaks of foils containing PLA+ Al NANO



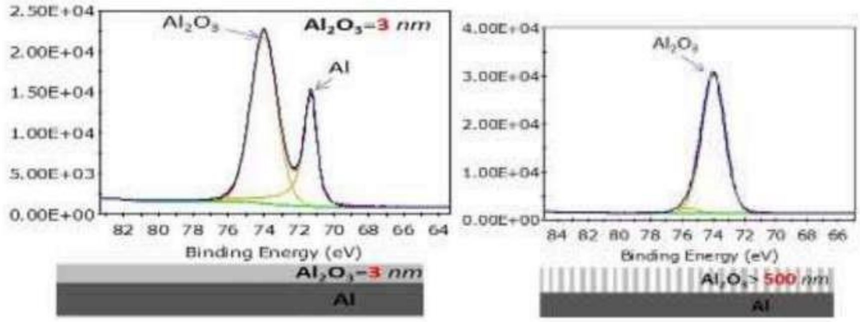
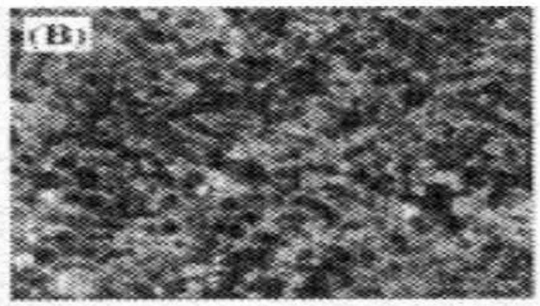
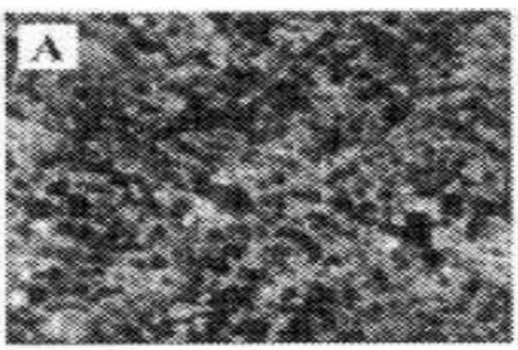


Figure 3: Structure of foils at 12,24^{0}CTemperatures

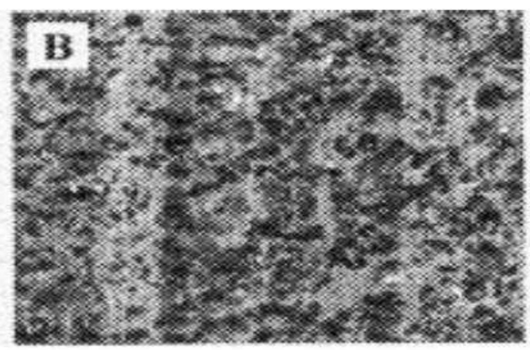
Surface finish before 24^{0}C film at 60 μm



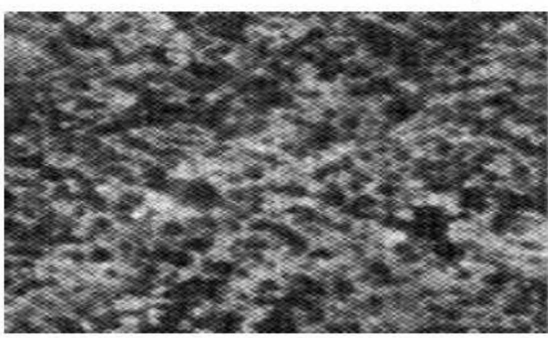
Surface finish after 24^{0}C film at 60 μm



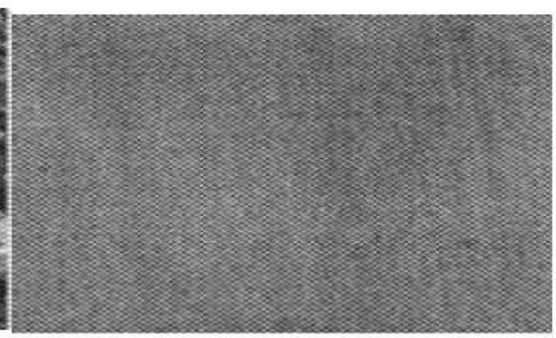
Surface finish before 12^{0}C film at 60 μm



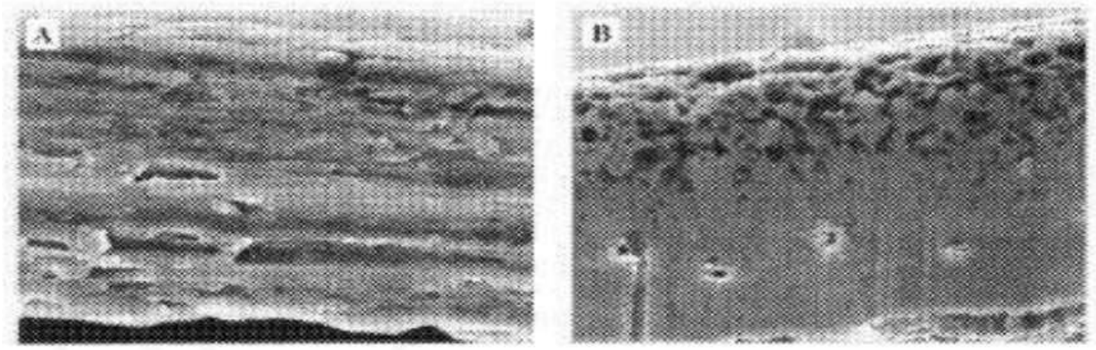
Surface finish after 12^{0}C film at 60 μm



Surface finish before 36^{0}C film at 60 μm

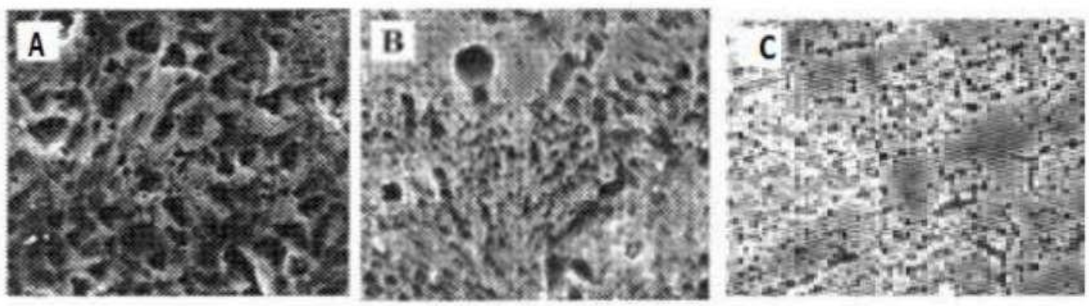


Surface finish after 36^{0}C film at 60 μm

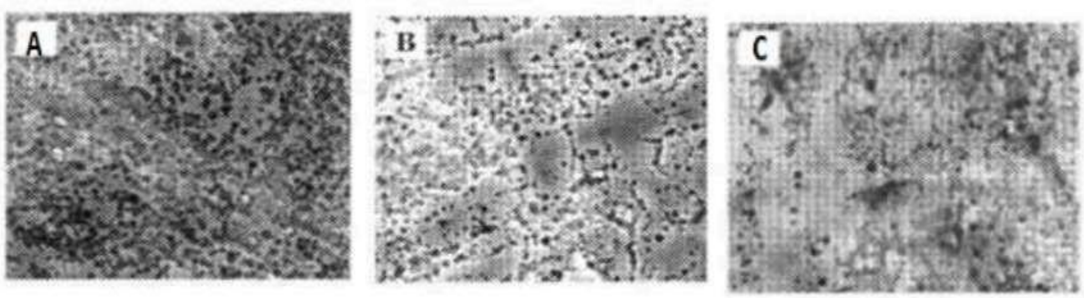


Surface finish before 50^0C film at 60 µm   Surface finish after 50^0C film at 60 µm

Structure of foils before and after chemical wash

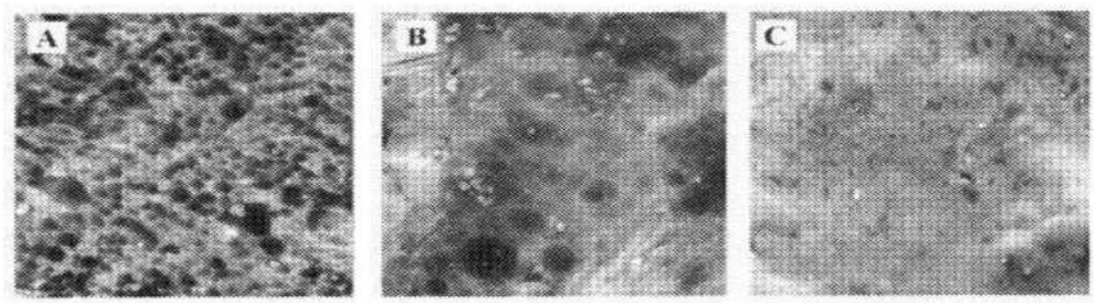


Before chemical wash   Process of chemical wash 100 µm After chemical wash 100 µm

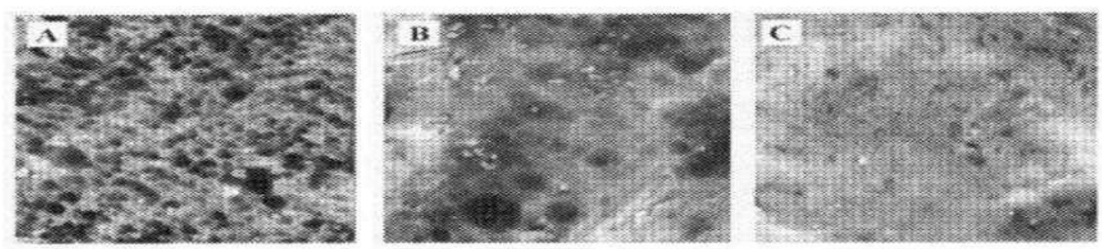


Before chemical wash 80 µm Process of chemical wash 80 µm After chemical wash 80 µm

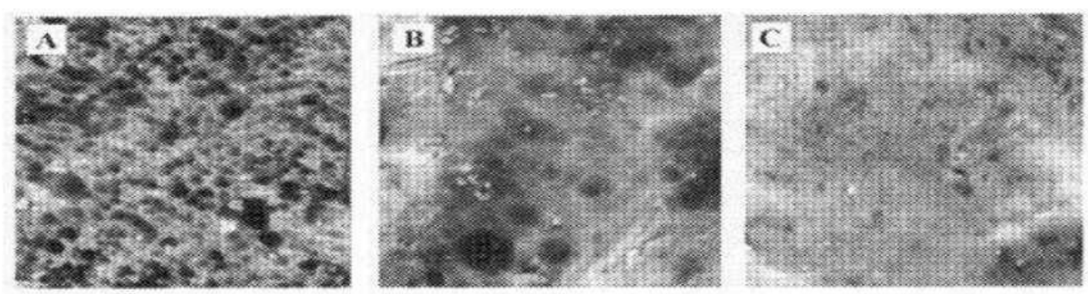
Stock solution (1000 ppm) was prepared using distilled water. 0.1M HCL and NaOH were used to adjust the initial pH of the dye solution.Na-Cl was used as a supporting electrolyte. Conductivity and pH of dye solution were measured using a conductivity meter.



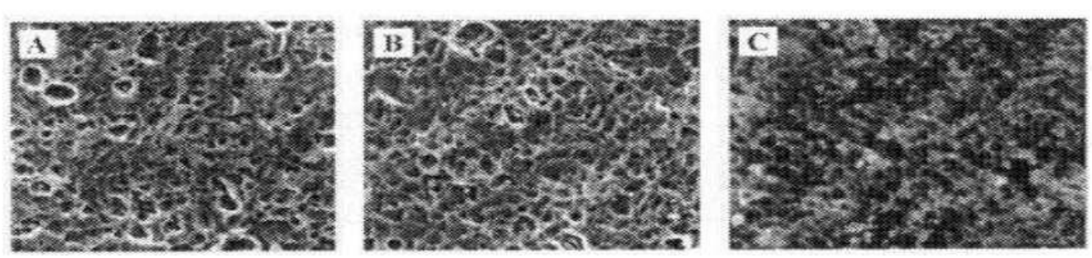
Before chemical wash of 60 μm process of chemical wash 60 μm After chemical wash 60 μm



Before chemical wash 50 μm Process of chemical wash 50 μm After chemical wash 50 μm



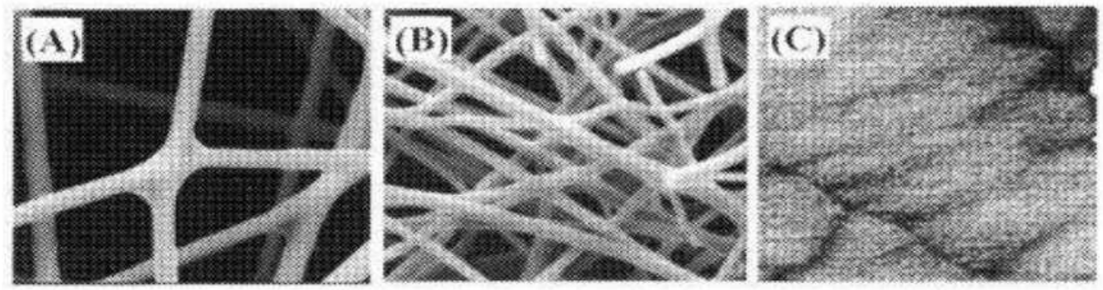
Before chemical wash 50 μm Process of chemical wash 50 μm After chemical wash 50 μm



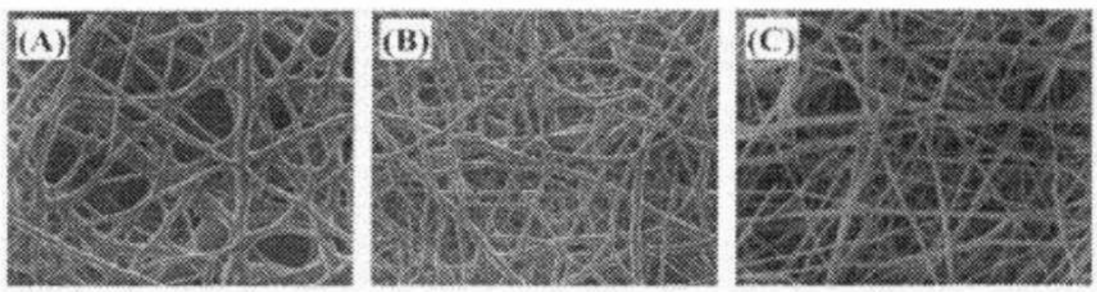
Before chemical wash 30 μm Process of chemical wash 30 μm After chemical wash 30 μm

S.no	Special Thickness(μm)	Tensile -Uts (MPa)	Burest strngth
1	30	23.2	Low
2	50	28.11	Low
3	60	30.61	Medium
4	80	38.31	Medium

5	100	42.33	High



Biodegradable after 15 days



Biodegradable after 30 days

5. Simulation results

Evaluation from the experimentation the resultant load conditions on foil at thickness 60μm 30.61MPa. The results will simulate the strength of foil at different load conditions up to 100N. Transient thermal analysis is the evaluation of how a system responds to fixed and varying boundary conditions over time. For fixed boundary conditions, the time to reach a steady state temperature can be evaluated, as well as how long operating conditions can be sustained before reaching a threshold temperature. For time-varying boundary conditions, transient analysis can show you the resulting thermal response of the system. A static structural analysis calculates the effect of steady (or static) loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can include steady inertia loads (such as gravity and rotational velocity and accelerations), and time varying loads that can be approximated as static equivalent loads.

Present simulation results are the evaluation of both structural and thermal loading conditions on foil at 300 gm at hot condition to check the resistance of PLA nano foil.

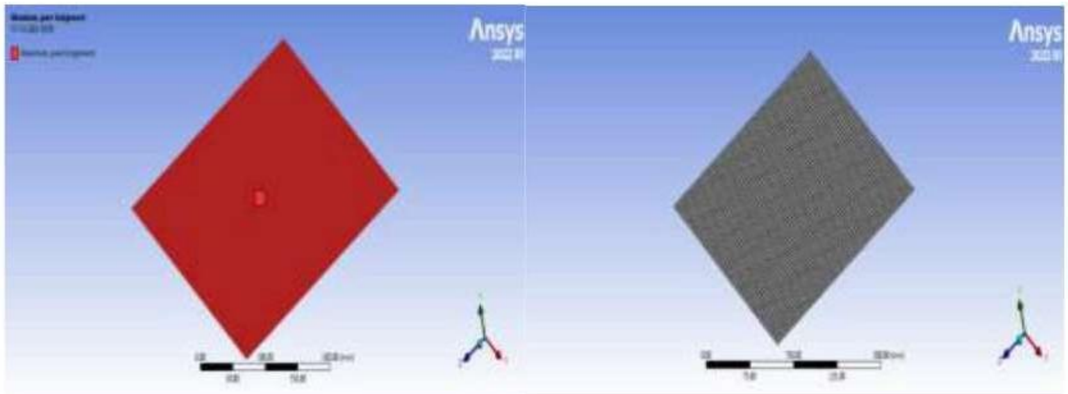
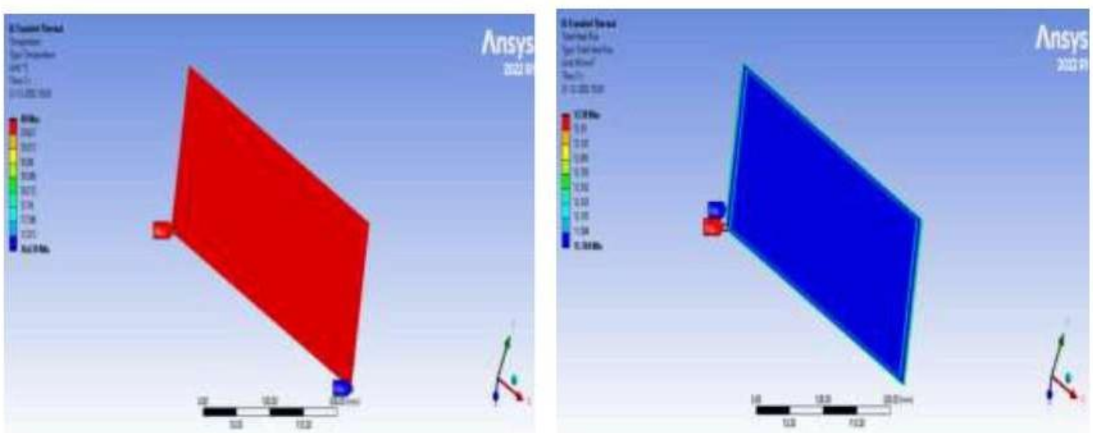
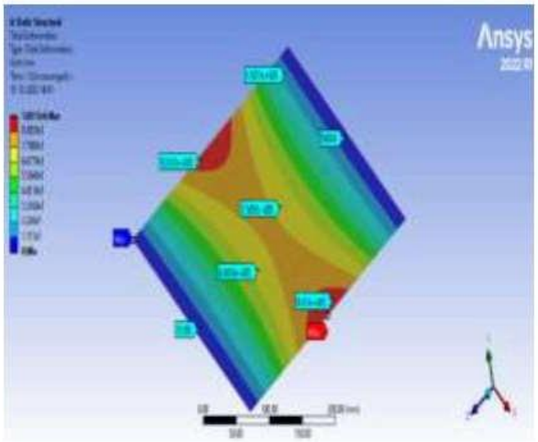


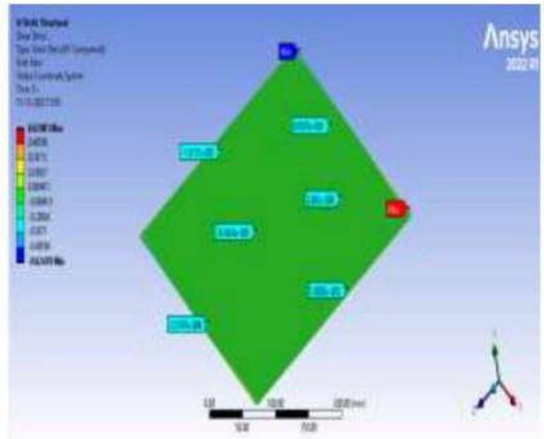
Figure: Nano alumina-PLA foil and meshing of the foil

The assignment of materials as well as meshing has been done with element size of 5mm on surface and 0.06mm for side as shown in figure.



Aluminum has a high specific heat capacity it can absorb a 400C of heat energy before it increases in temperature. This allows the applied heat to be distributed evenly throughout the foil, causing it to heat up quickly and uniformly.





In this figure shown than the strain was computed is more than the yield stress of the model, which is known as Vonmises-stress. FEA predicts the areas where the maximum stress value is reached 0.62481 max for 6N load.

Parameters	3N	6N	9N
Total Deformation	1.53	4.429	2.226
Equivalent Elastic Strain	3.8531	4.9781	6.3547
Shear Stress	0.226	0.208	0.192

	12^0C	36^0C	40^0C	50^0C
Temperature	13.88	36.	40.	50.
Total Heat Flux	7.5337	10.56	13.58	21.135
Thermal Error	9.3365	18.369	30.389	73.655

S.No	Special Thickness(μm)	Tensile -Uts (MPa)	
		Experimental	Simulation
1	30	23.2	24.6
2	50	28.11	28.42
3	60	30.61	31.22
4	80	38.31	38.66
5	100	42.33	42.56

6. Conclusions

PLA based Nano foils has been investigated in the present work, micro-structures, thermal stability, biodegradability and load effects tested for different thickness foils. Comparative analysis of strength and durability tested at temperatures below and higher temperatures of ambient. The results discussed with 30 days degradable in soil. Food preservation considered with chemical and thermal tests 60 micron foil given good result.

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