

Properties Evaluation of Natural Weathered Polyester/Nano-Locust Bean Pods Ash (LBPA) Composite

B.O. Araoye* A. Kasim M. Abdulwahab U. Shehu
Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, Nigeria

Abstract

Nano-Locust bean Pod Ash (LBPA) reinforced polyester matrix composite was developed via Sol-gel techniques to investigate the mechanical and physical properties of the composite after weathering. The mechanical and physical test samples were prepared according to ASTM standard. The composite were subjected to weathering tests to study the effect of natural weather and its degradation on the properties of the composites. The moisture absorption of the composite after 24 hours as well as the weight loss of the test samples after degradation was evaluated. Percentage water absorption of the composite increased with increase in percentage reinforcement composition. The percentage weight losses also increase as the percent reinforcement in the composite increases. Weight loss of the test samples after 30 days shows the highest weight loss values. Approximately 54%, 11%, 86%, and 43% drop in values after 90days exposure was recorded for impact, tensile, flexural and hardness test values respectively. The reduction in modulus values recorded for tensile and flexural was approximately 51% and 8%.

Keywords: Nanosized LBPA; polyester composite; Natural weathering; Properties

1. Introduction

Composite materials, plastic and ceramics have been the dominant emerging materials. The number of applications of composites, particularly polymeric composites reinforced with synthetic fibers such as glass, carbon and aramid has grown steadily due to their unique properties of high hardness and strength-to-weight ratio (Mishra *et al.* 2002). The widespread use of synthetic fiber reinforced polymer composites has a tendency to decline because of their high initial costs and more importantly their adverse environmental impact (Mishra *et al.* 2002; Mohanty & Drzal, 2001). Today, the growing environmental awareness throughout the world has triggered a paradigm shift from synthetic fibers and their composites towards composites made from natural reinforcing constituents; natural fiber and natural particulate fillers which are more environmentally friendly (Wretfors & Svennerstedt, 2006).

In recent times, the trend in developing a composite material using byproduct as reinforcement has been a worthy area of interest because of their easy access, low cost and low biodegradability. Today, research in polymer science and engineering is chiefly focused on composites made from renewable resources (Mohanty *et al.* 2000).

Locust bean pods are readily available in most part of Nigeria due to the high consumption of locust bean seed (Karwa-Hausa; Ngin-Ham; Iyere-Yoruba as it is natively called) across the country. The pods constitute waste and environmental pollution. The use of locust bean pod ash (LBPA) nanoparticles has not been extensively study. Hence, the present study, investigate the impact of natural weathering on the mechanical properties of LBPA nanoparticles filled polyester composites before and after degradation and evaluates the percentage water absorption and percentage weight losses after weathering.

2. Experimental Procedure

2.1 Materials

The materials used in this research include: Locust bean pods ash (*Pakia biglobosa*) particulates, unsaturated polyester resin, HCl, NaOH, ethanol, Cobalt accelerator and methyl-ethyl ketone catalyst.

2.2 Nanoparticles Preparation

The locust bean pods (*Pakia biglobosa*) were sourced locally, washed to remove dirt and sun dried. The pods were ground and then ashed at 600 °C for 2 hours. The nano-LBPA was produced by the Sol-gel technique. The produced ash was mixed with 2.5 M NaOH solution, boiled for 3 hours at 90 °C with constant stirring. The particles were then filtered and mixed thoroughly with 2% HCl solution; refluxing of the mixture, followed for 4 hours at 90 °C; the particles removed, filtered, washed with distilled water and dried. The particles were then heated in a heat-treatment furnace at 600 °C for 5 hours.

2.3 Composite Preparations

To develop the composite, polyester resin was first thoroughly mixed with cobalt accelerator (10%) and methyl-ethyl ketone catalyst (10%). Releasing agent was used inside the mold cavity to ease the removal of the solidified samples. The polyester resin was mixed with and without reinforcement, after addition of the accelerator and catalyst. The nano-LBPA were varied at 0wt% to 12wt% (at intervals of 3wt%) to produce the polyester/nano-

LBPA composite. After proper stirring, the homogenous mixture was poured into a prepared mold and left at room temperature until it settled. After cooling and solidification, it was removed from the mold, cured by heating in an oven at 70 °C for 2 hours and then cooled in still air.

2.4 Degradability Test

Degradability test of the developed composite was carried out to assess the influence of natural weather on the samples. Samples were prepared according to the required test sizes of tensile, hardness, impact and flexural. Specimens were then exposed to natural weather using the customized weather rackets method (samples were suspended with the aid of a copper wire) for 90 days after which they were removed at intervals of 30 days and their properties evaluated using the below discussed tests; their weight loss was also computed.

2.5 Mechanical Testing

(a) Impact Test: The impact energy test of the polyester composite samples was determined using a Charpy impact testing machine. The procedure used was in accordance with that recommended by ASTM 256 and the impact strength calculated.

(b) Tensile Test: The test was performed in accordance with standard procedure specified in ASTM D638 using the Hounsfield Tensometer. The tensile strength and tensile modulus was calculated using

$$\sigma = \frac{F}{A} \quad (1)$$

$$\epsilon = \frac{\sigma}{E} \quad (2)$$

Where σ is the tensile stress, F = load (N), A is cross-sectional area of the sample, ϵ is the tensile or young modulus and E is the tensile strain.

(c) Flexural Test: The Flexural tests were conducted to determine the flexural properties of the polyester composite. The Samples were subjected to bending by supporting them at both ends and a midpoint load applied until failure as recommended in ASTM D790. The flexural strength(σ_f) was calculated using

$$\sigma_f = \frac{3FL}{2bd^2} \quad (3)$$

Where F is the load (N), L is the length of the support span (mm), b is the specimen width (mm), and d is the specimen thickness (mm). The flexural modulus (E_f) was calculated using

$$E_f = \frac{FL^3}{4bH^3d} \quad (4)$$

Where H is height, d is deflection and other parameter remains as above.

(d) Hardness Test: The Hardness tests of the samples were carried out using a Rockwell hardness testing machine on F scale (HRF). The test was carried out in accordance with the procedure described by ASTM D785. 10kgF of minor load was applied followed by the major of 60KgF. The hardness value of each sample, digitally displayed, was recorded.

2.6 Water Absorption Test

Water absorption of the composites was determined using the procedure recommended by ASTM D570. The samples were weighed (W_1) before immersion in distilled water and after 24hour, they were removed, cleaned and dried with blotting paper and final weight (W_2) recorded.

$$\% \text{ Moisture Content} = \frac{W_2 - W_1}{W_1} \times 100 \quad (5)$$

2.7 Weight Loss Evaluation

The test samples used were weighed before (initial weight, W_0) and after (final weight, W_t) weathering and the percentage weight loss evaluated using the equation below:-

$$\% \text{ Weight loss} = \frac{W_0 - W_t}{W_0} \times 100 \quad (6)$$

2.8 Surface Morphology Analysis

The fracture surface of the test samples and the synthesized Nano-Locust Bean Pod Ash (LBPA) particles were studied using Scanning electron Microscope (SEM – model: Phenom ProX).

3. Results and Discussion

3.1 Results

Figure 1 and 2 shows the impact strength profile of the weathered and non-degraded polyester/Nano-LBPA composite samples. While Figures 3–12 depicts the tensile strength/modulus, flexural strength/modulus and hardness of the non-degraded and degraded (weathered) polyester/Nano-LBPA composite samples. Figures 13–17 indicates the percentage water absorption and percentage weight loss of the mechanical tests (impact, tensile, flexural and hardness) samples. While Figure 18 shows the micrograph of the synthesized nanoparticles developed

from LBPA particle. In Figures 19 and 20, the micrographs of the fracture surface after natural weathering degradation and water absorption test samples were presented.

3.2 Discussion

3.2.1 Impact Strength

From the Figures for the impact test, it could be seen that a decrease in impact strength was observed with a corresponding increase in percentage LBPA reinforced polyester composite. It was also observed that the impact strength of the weathered polyester composite dropped sharply from 50 J/m (at 0%LBPA) after 30 days to 23 J/m (at 12%LBPA); approximately 54% decrease after 90 days. The addition of LBPA has enhanced the biodegradability of the polyester, mainly because they are renewable materials which are also degradable as report elsewhere (Singh *et al.* 2003). Fluctuations were observed with an increase in impact strength value from 23 J/m (at 6%LBPA) to a maximum value of 25 J/m (at 9%LBPA) approximately 8% rise in value after 30 days, from 30 J/m (at 6%LBPA) to a value of 35 J/m (at 9%LBPA) approximately 16% after 60 days, and from 22 J/m (at 9%LBPA) to a value of 23 J/m (at 12%LBPA) approximately 4% increase after 90 days of exposure. The impact strength of the non-degraded composite samples were found to increase with increase percentage particle loading (0%LBPA to 12%LBPA) – approximately 18%, but 6%LBPA was noted to exhibit the highest impact strength value (Figure 2). This might also be due to increased polymer-filler interaction as attested by (Karmakar & Hoffmann, 1994; Shenoy & D'Melo, 2007 in Rashdi *et al.* 2009). However, there was a general decrease in impact strength values of the polyester composite samples with increase in LBPA addition after weathering. This result indicates that the degradation of LBPA is faster than that of polyester matrix; this might be because weathering has induced cracks, possibly due to the swelling and shrinkage of the particles and weakening of the bonds between particles-polyester matrix as established (Cao *et al.* 2002; Kim *et al.* 2006).

3.2.2 Tensile Properties

The tensile strength and modulus of the samples decreased marginally from 28 MPa to 25 MPa, 0.2 GPa to 0.19 GPa (at 0%LBPA) with maximum reduction found to be approximately 11% and 35% respectively after exposure for 30–90 days (Figure 3 and 4). General reduction was observed in the tensile modulus value of the degraded samples. The drop in modulus was found to be approximately 51% after exposure for 30–90 days (Figure 4). This may be due to the fact that when the composite is exposed to moisture, the hydrophilic LBPA swelled as a result, it undergo desorption and absorption which consequently affect the composite samples. This is similar to earlier report (Obasi, 2012). Some fluctuations were observed in the tensile strength values; from 12 MPa (at 6%LBPA) to 14 MPa with approximately 17% increase (at 9%LBPA) after 30 days, 12 MPa (at 9%LBPA) to 14 MPa approximately 17% (at 12%LBPA) after 60 days, and finally from 6 MPa (at 6%LBPA) to 12 MPa (at 12%LBPA) after the exposure period (Figure 3). This indicated that there was some degree of interactions between the particle and the polymer matrix of the composite which might be responsible for the anomalous increase in tensile strength value. This agrees with earlier reports (Shenoy & D'Melo, 2007). The tensile strength and modulus of non-degraded samples exhibit enhanced properties; with an increase in their value as the percentage particle loading increases (Figure 5 and 6). This might be due to the increase in the surface area that is possible from fine particles compared to large ones as reported elsewhere (Oladele & Adewole, 2013). Except for 3%LBPA (tensile strength) and 9%LBPA (modulus of elasticity) which exhibit a decrease in property probably due to poor interfacial adhesion between the matrix and reinforcement of these samples as established earlier (Abdulkhilil *et al.* 2010).

3.2.3 Flexural Properties

The flexural strength decreased with an increase in LBPA addition from 62.13 MPa (at 0%LBPA) after 30 days to 8.73 MPa (at 12%LBPA) – approximately 86% reduction after 90 days exposure; with their respective modulus found to be 1.2 GPa to 1.1 GPa – approximately 8% (Figure 7 and 8). The lowest flexural strength and flexural modulus values of 4.92 MPa and 0.4 GPa was obtained at 3%LBPA after 90 days of exposure. The decrease in the flexural strength of the composites can be explained on the basis of agglomerate formation; the presence of these agglomerates increased the flaws in the composite. The flaws became larger in size and wetting of the filler by the matrix phase occurred, thus forming the voids between the filler and the matrix polymer; these accelerated the rates of water absorption and caused more damage to the composite samples (Abdulkhilil *et al.* 2010; Ana *et al.* 2004; Ismail *et al.* 2003). A significant increase in flexural strength values was observed in the polyester composite samples after 30 days at 9%LBPA which increase from 11.36 MPa to 26.02 MPa at 12%LBPA; 60 days at 9%LBPA which increase from 14.24 MPa to 23.00 MPa at 12%LBPA and finally for 90 days at 6%LBPA which increase from 9.60 MPa to 10.37 MPa at 9%LBPA. Their modulus values were observed to increase from 0.8 GPa to 1.2 GPa; 0.5 GPa to 0.6 GPa and 0.5 GPa to 0.7 GPa respectively (Figure 7 and 8). The results obtained show that pure polyester samples exhibit the highest flexural strength behavior due to the matrix properties which displayed more ductility than the test composite samples. The addition of natural particulate filler to the polymer matrix has increased the degradation properties of the matrix and has also introduced stiffness to the polymer matrix composite, thus reducing the flexibility of the composite. From Figure 9 and 10, the flexural strength and flexural modulus of non-degraded samples exhibit an increase in value from 10.75 MPa at 0%LBPA to 14.17 MPa

at 12%LBPA and 1.1 GPa at 0% to 1.4 GPa at 12%LBPA. Similar results had been reported earlier (Oladele & Adewole, 2013).

3.2.4 Hardness

In Figure 11, the minimum hardness value of 6.4 HRF (at 6%LBPA for 90 days) was obtained and a maximum value of 11.6 HRF (at 0%LBPA for 30 days). It can also be seen that there is a fluctuation in the hardness values of the test samples. The pure polyester samples (Figure 11) had the highest hardness values for the entire period of exposure compared to the composite samples. This might be due to the degradation of the composite after being attacked by ultraviolet light. This is similar to earlier report (Facca *et al.* 2006; Kim *et al.* 2006). Decrease in hardness value with increase percent particle loading was also observed for non-degraded samples (Figure 12). This agrees with earlier reports (Shehu *et al.* 2014). The general reduction in mechanical properties of the polyester/nano-LBPA composite can be attributed to the degradable nature of the filler used.

3.2.5 Percent Water Absorption

Figure 13 shows the percentage of weight gained as a function of time for these test samples. From the curve, it could be noted that the water absorption, increased as volume fraction of the LBPA increase in the composite samples. This phenomenon can be explained by considering the water absorption characteristics of natural fillers, when the composite is exposed to moisture, the hydrophilic nature of the reinforcement makes it swell; water which has a density of 1kg/m^3 also contributes to the weight gain by the composite. As a result, weight gain in the composite samples was observed. The attack of the composite by water molecules resulted in debonding the matrix from the reinforcement. This agrees with earlier research (Dhakal *et al.* 2007).

3.2.6 Percentage Weight Loss

Figure 14–17 shows the trend of the weight loss of the polyester composite samples. The tensile and flexural tests samples both shows lowest weight loss values of 0.31% and 0.05% at 0%LBPA over the 90 days exposure period. For impact test samples, 6%LBPA exhibit the lowest weight loss of 0.25% after exposure for 30 and 90 days respectively. Similarly, at 12%LBPA, the highest weight loss of 1.24% was obtained after 30 days of exposure for hardness test samples. However, the observed weight loss was prominent for 12%LBPA samples. This might be attributed to the increase in water uptake of the composite samples which causes deterioration that result in reduced sample's mass and mechanical properties (Abdulkhalil *et al.* 2010).

3.2.7 Nanoparticle Determination

In Figure 18, SEM micrograph at 20000x magnifications shows a minimum average particle of 52.4nm in size indicating a nanoparticle sized of the synthesized LBPA achieved in this study. Although there were formation of agglomerates by the particles which could have affected the properties of the composite samples. Equally, it has been stated that nanoparticles in an agglomerate state, behave as larger particles, depending on the size of the agglomerate (Cristina *et al.* 2007).

3.2.8 Surface morphology analysis

Figure 20 shows the micrograph of the composite after testing for water absorption (at 12%LBPA for 24 hours). There were agglomerate of particles as observed from the microstructure; similar observation was noted in the micrograph of the composite samples exposed to natural weather. This might be due to poor dispersion of particles in the matrix phases, leading to the formation of agglomerates. The presence of these agglomerates might have facilitated higher rate of water/moisture absorption by the composite; thus weight gain by the swelled particles would consequently cause increase in weight of the polyester matrix composite as established elsewhere (Mat-Taib *et al.* 2010). The microstructure of the polyester/nano-LBPA composite fractured surface after degradation displayed a roughed surface with pore sizes noted to be an average of $83.87\mu\text{m}^2$ (Figure 19). LBPA is a hydrophilic material and has the tendency to undergo swelling and shrinkage due to absorption and de-sorption of moisture during weathering period. The LBPA particles that are not encapsulated by the polyester matrix could easily absorb moisture from the environment and from the rainfall–swelling pressures of the swelled LBPA particles occur. This might simultaneously lead to lowered mechanical properties observed (Mat-Taib *et al.* 2010; Mehdi *et al.* 2010). This attests to the result presented above.

4. Conclusions

- i. Weather, temperature, humidity and degradation process significantly influenced the physical and mechanical properties of the test composite.
- ii. Nano-LBPA particle has been demonstrated to be an effective bio-reinforcement for polymer matrix composite.
- iii. The surface morphology of the fractured surface and the Nanoparticles shows the presence of agglomerates within the structure; minimum particle size of 52.4nm was achieved from the synthesized nanoparticles.
- iv. The mechanical properties of the composite after weathering decreases as the percentage reinforcement increases.

References

- AbdulKhalil, H.P.S., Poh, B.T., Jawaid, M., Ridzuan, R., Suriana, R., Said, M.R. & Nick Fuad, N.A. (2010). The Effect of Soil Burial Degradation of oil Palm Trunk Fiber-filled Recycled Polypropylene composite. *Journal of Reinforced Plastics & Composites* DIO: 101177/0731684409102939 Vol. 29, 1653.
- Ana, E., Francisco, V. & Singbritt, K. (2004). Comparison of Water Absorption in Natural Cellulosic fibers from Wood and One-year Crops in Polypropylene Composites and its Influence on their Mechanical Properties. *Composites. Part A: Applied Science & Manufacturing* 35, 1267-1276.
- Cao, A., Okamura, T., Nakayama, K., Inoue, Y. & Masuda, T.. (2002). Studies on syntheses and physical properties of biodegradable aliphatic poly (butylenes succinate-co-ethylene succinate) s and poly (butylenes succinate-co-diethylene succinate) s. *Polymer Degradation & Stability* 78, 107-117.
- Cristina, B., Ivan, I.P.B. & Kevin, R. (2007). Nanomaterials and Nanoparticles: Sources and Toxicity. *Biointerphase* Vol. 2 issues 4, 17-172.
- Dhakal, H.N., Zhang, Z.Y. & Richardson, M.O.W. (2007). Effect of water absorption on the mechanical properties of hemp fiber reinforced unsaturated polyester composites. *Composites Science & Technology* 67, 1674-1683.
- Facca, A.G., Kortschot, M.T. & Yan, N. (2006). Predicting the elastic modulus of natural fiber reinforced thermoplastics. *Comp. Part A-AP. Science & Manufacturing* 37, 1660-1671.
- Ismail, H., Hong, H.B., Ping, C.V. & AbdulKhalil, H.P.S. (2003). Polypropylene/silica/Rice Husk Ash Hybrid composites. A study on Mechanical, Water Absorption and Morphological properties. *Journal of Reinforced Plastics & Composite* 16, 121-137.
- Karmakar, A.C. & Hoffmann, A.G.H. (1994). Influence of Water Absorption on the Mechanical Properties of Jute Fiber Reinforced Polypropylene. *Journal of Applied Polymer Science* 54, 1803-1807.
- Kim, H.S., Hyun, J., Kim, J.W.L. & In-Gyu Choi. (2006). Biodegradability of bio-flour filled biodegradable poly (butylenes Succinate) bio-composites in natural and compost soil. *Polymer Degradation & Stability* 91, 1117-1127.
- Mat-Taib, R., Ahmad, N.S.Z., Mohd-Ishak, Z.A. & Rozman, H.D. (2010). Effects of photo-stabilizers on the properties of recycled High Density Polyethylene (HDPE) /wood flour (WF) composites exposed to natural weathering. *Primalaysia polymer Journal* Vol. 5 No. 2, 193-203.
- Mehdi, B., Abdolreza, K., Shahrzal, K., Abdolraoul, O. & Amir, H.O.J. (2010). Microbial biodegradable potato starch based Low Density Polyethylene. *African Journal Biotechnology* Vol. 9 (26), 4075-4080.
- Mishra, S., Tripathy, S. & Nayak, S. (2002). Novel Eco-friendly Biocomposites, Biofiber reinforced Biodegradable polyester amide composite-fabrication and properties evaluation. *Journal of Reinforced Plastic Composite* Vol. 21 No. 1, 55-70.
- Mohanty, A.K. & Drzal, L.T. (2001). Surface modification of natural Fibers and Performance of the Resulting Biocomposites. *An overview-composite interface* Vol. 8 No.5, 313-343.
- Mohanty, A.K., Misra, M. & Drazal, L.T. (2000). "SAMPE, advanced composite technology for 21st century transportation," in *Proceedings of the Midwest Advanced Materials & Processing Conference*, Dearborn, Michigan
- Obasi, H.C. (2012). Studies on Biodegradability and mechanical properties of High Density Polyethylene/Corncob Flour Based Composites. *International Journal of Scientific and Engineering Research* Vol. 3 Issue 8, ISSN2229-5518.
- Oladele, I.O. & Adewole, T.A. (2013). Influence of cow bone particle size distribution on the mechanical properties of cow bone-reinforced polyester composite. *Biotechnology Research International* Volume 2013, 1-5 <http://dx.doi.org/10.1155/2013/725396>.
- Rashdi, A.A.A., Sapuan, S.M., Ahmad, M.M.H.M. & Khalina, A. (2009). Water absorption and tensile properties of soil burial kenaf fiber reinforced unsaturated polyester composite (KFRUPC). *Journal of Food, Agriculture & Environment* 17 (3 and 4), 908-911.
- Shehu, U., Aponbiede, O., Ause, O.T. & Obiodunukwe, E.F. (2014). Effect of particle size on the properties of Polyester/Palm Kernel Shell (PKS) Particulate Composites. *Journal of materials & environmental science* Vol. 5(2), 366-373.
- Shenoy, M.A. & D'melo, D.J. (2007). Evaluation of mechanical properties of unsaturated polyester-guar gum/hydroxypropyl guar gum composite. *eXPRESS Polymer Letters* Vol. 1 No.9, 622-628.
- Singh, R.P., Pandey, J.K., Rutot, D., Degee, P.H. and Dubois, P.H. (2003). Biodegradation of Poly(ϵ -capoolactone)/starch blends and composites in composting and culture, environment: the effect of compatibilization on the inherent biodegradability of the host polymer. *Carbohydrates Researches*, 338, 1759-1769.
- Wretfors, C. & Svennerstedt, B. (2006). Bio-fiber Technology used in Military Applications. *An overview*. JBT Rapport No. 142, 1-40.

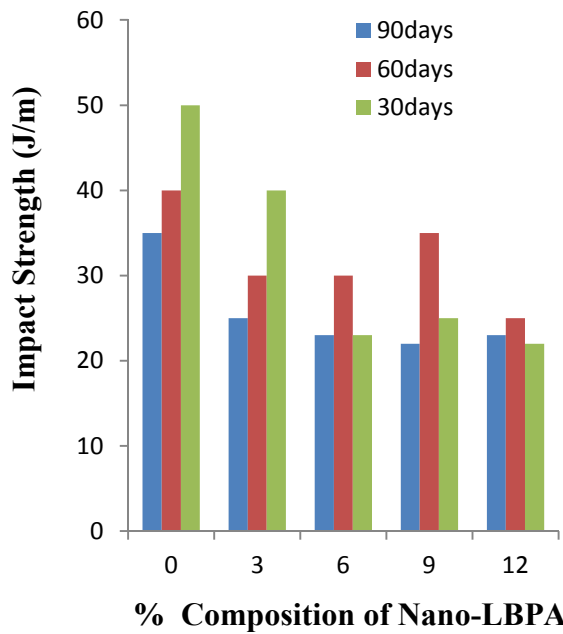


Figure 1: Impact strength profile of weathered polyester/Nano-LBPA composite for 30, 60 and 90 days.

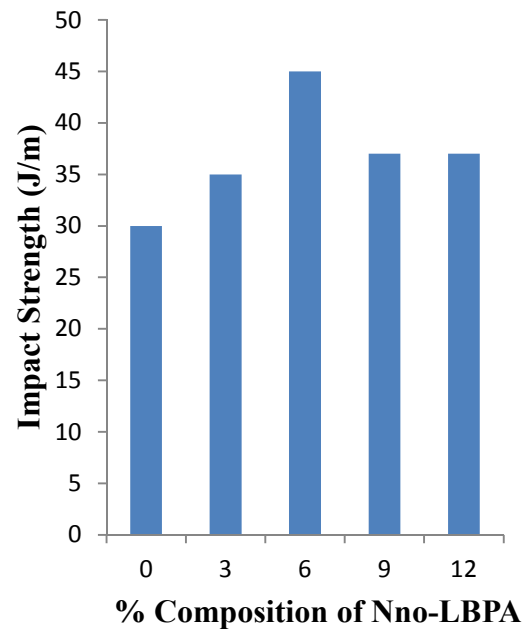


Figure 2: Impact strength profile of non-degraded polyester/Nano-LBPA composite.

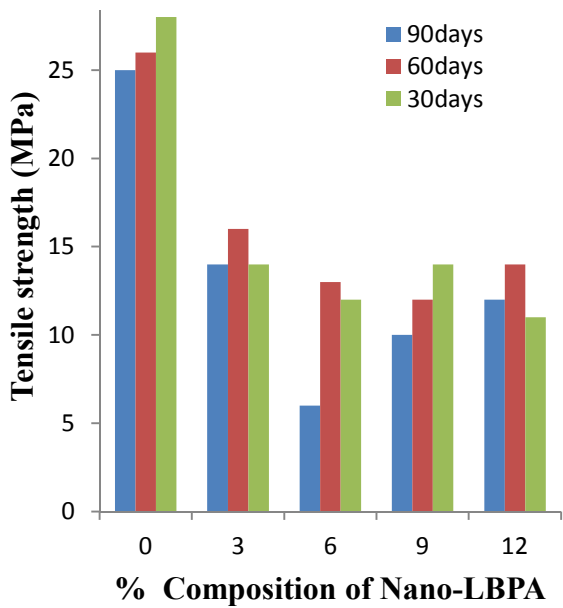


Figure 3: Tensile strength profile of weathered polyester/Nano-LBPA composite for 30, 60 and 90 days.

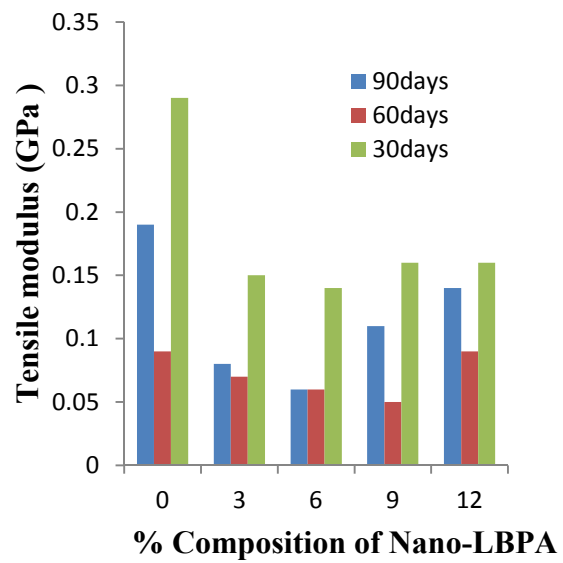


Figure 4: Tensile modulus profile of weathered polyester/Nano-LBPA composite for 30, 60 and 90 days.

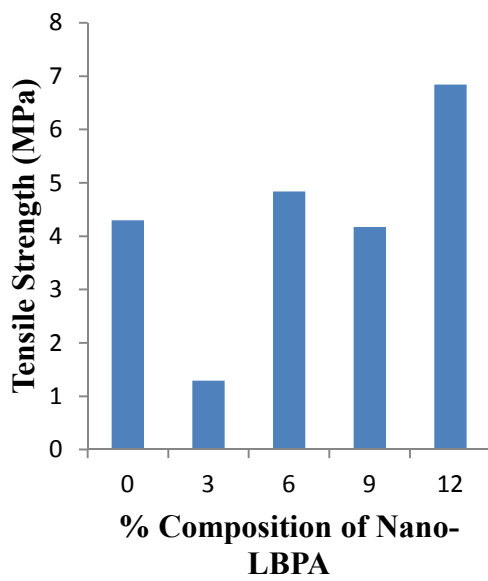


Figure 5: Tensile strength profile of non-degraded polyester/Nano-LBPA composite.

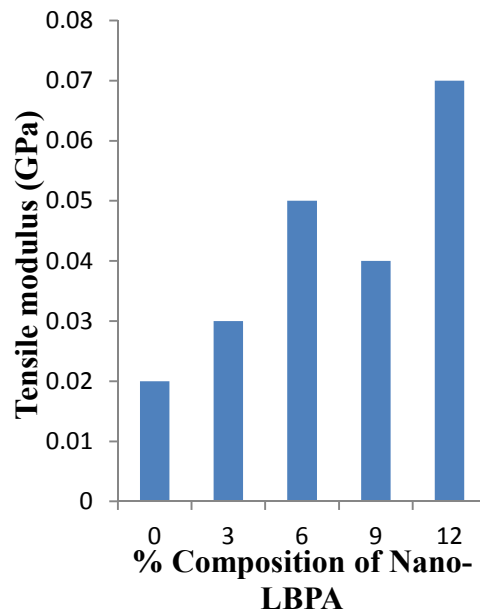


Figure 6: Tensile modulus profile of non-degraded polyester/Nano-LBPA composite.

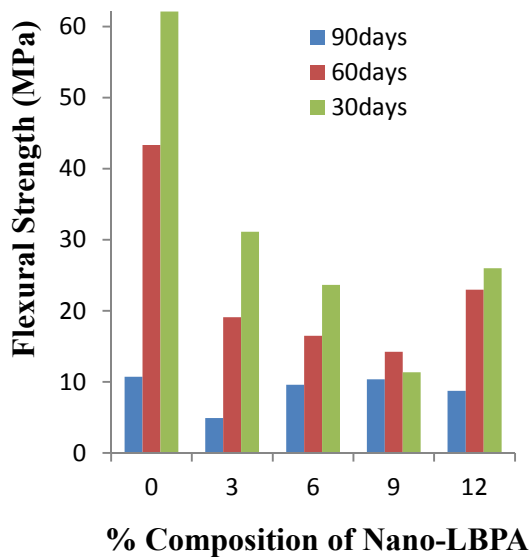


Figure 7: Flexural strength profile of weathered polyester/Nano-LBPA composite for 30, 60 and 90 days.

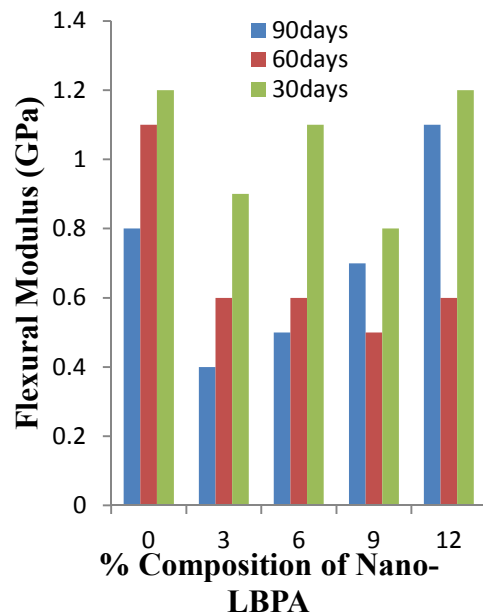


Figure 8: Flexural modulus profile of weathered polyester/Nano-LBPA composite for 30, 60 and 90 days.

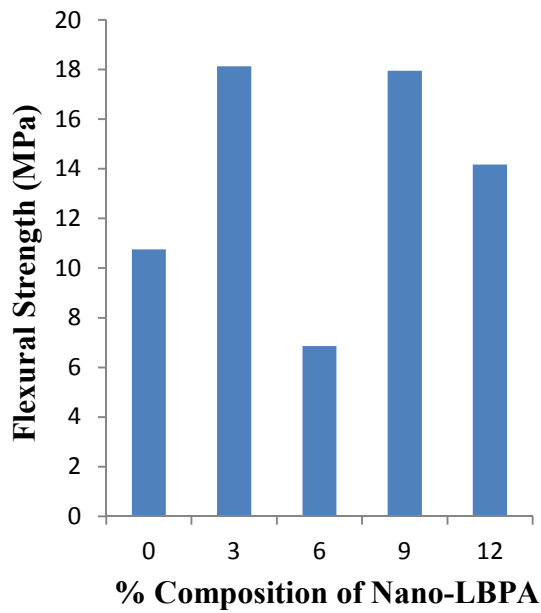


Figure 9: Flexural strength profile of non-degraded polyester/Nano-LBPA composite.

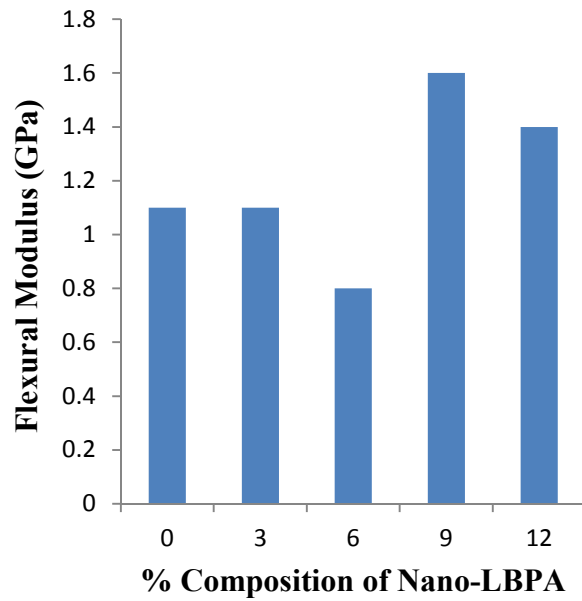


Figure 10: Flexural modulus profile of non-degraded polyester/Nano-LBPA composite.

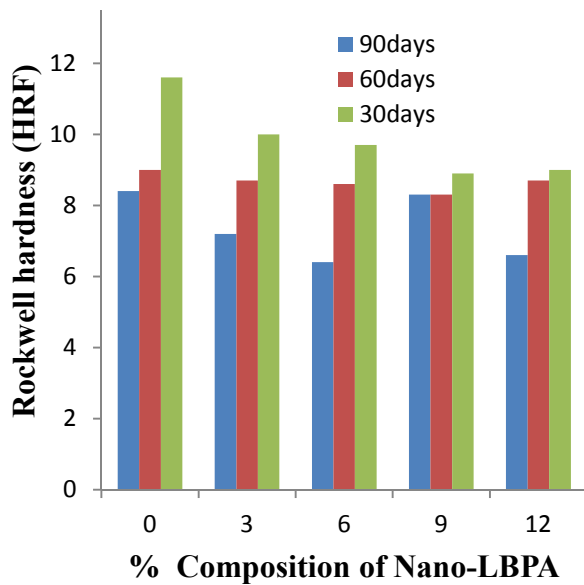


Figure 11: Hardness profile of weathered polyester/Nano-LBPA composite for 30, 60 and 90 days.

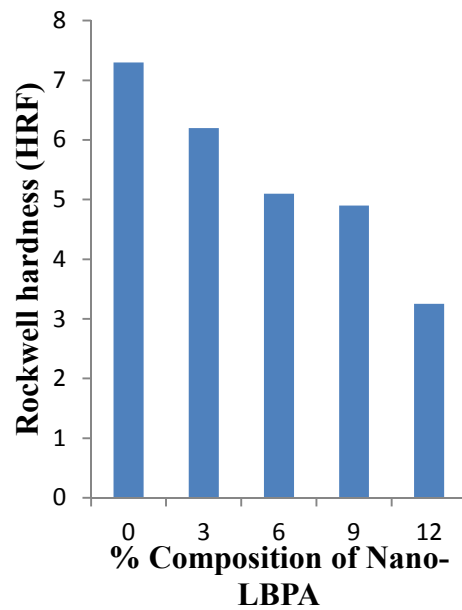


Figure 12: Hardness profile of non degraded polyester/Nano-LBPA composite.

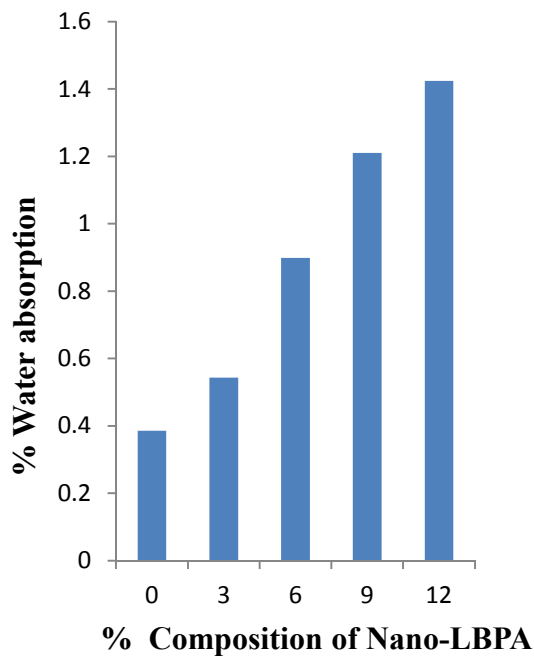


Figure 13: Percent Water absorption profile of polyester/Nano-LBPA composite after 24 hour.

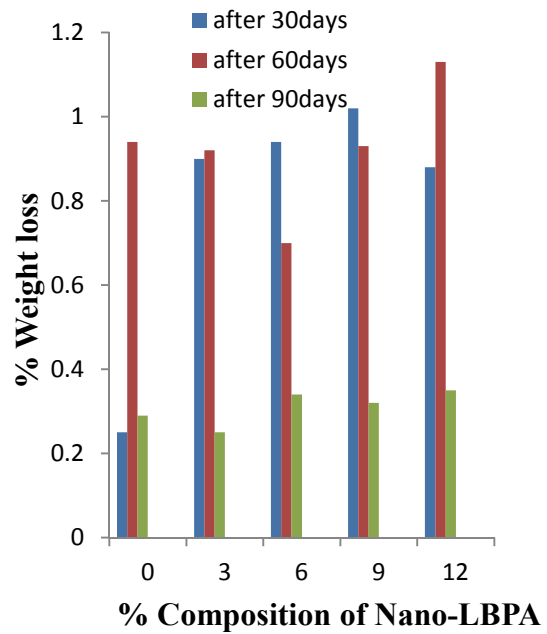


Figure 14: Weight loss profile of impact test samples after natural weather degradation.

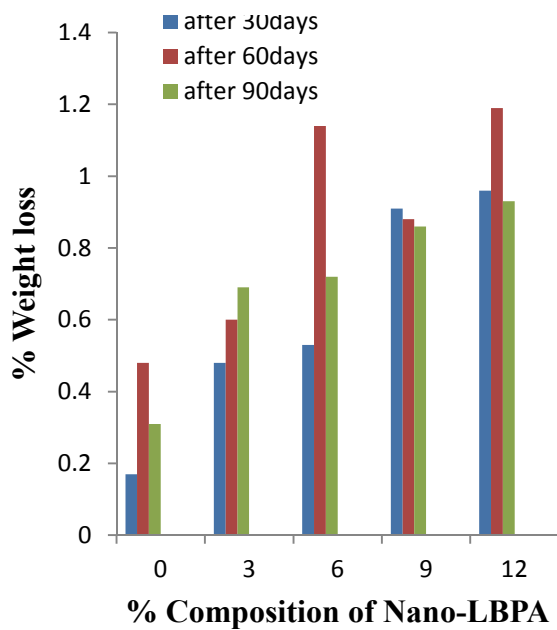


Figure 15: Weight loss profile of tensile test samples after natural weather degradation.

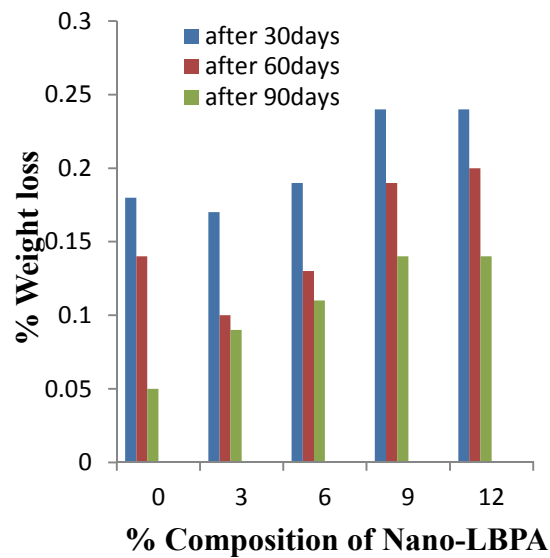


Figure 16: Weight loss profile of flexural test samples after natural weather degradation.

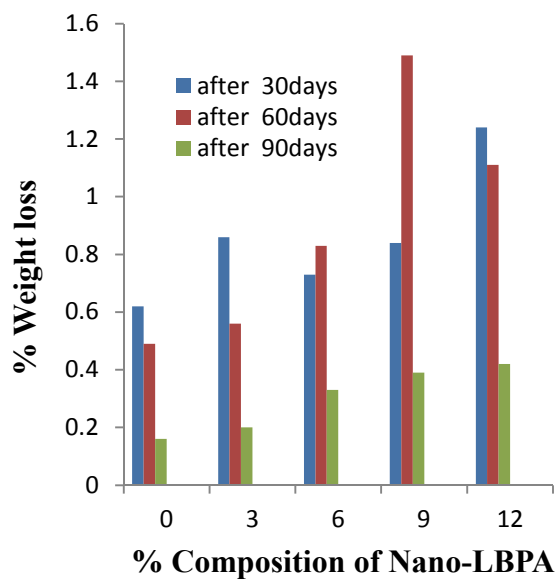


Figure 17: Weight loss profile of hardness test samples after degradation.

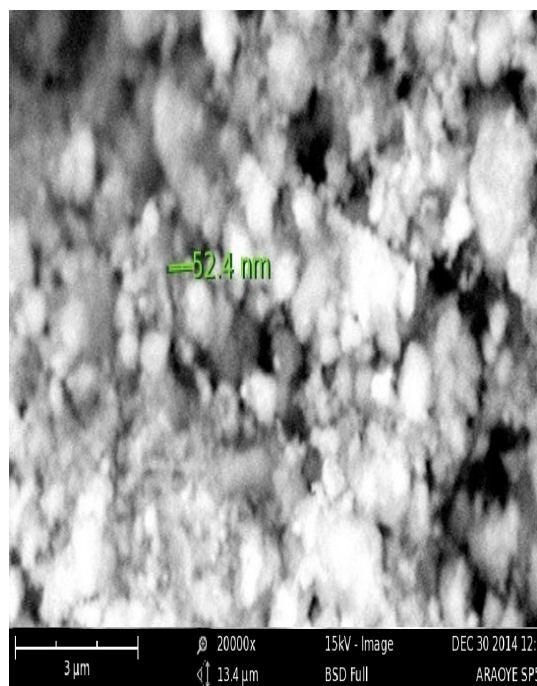


Figure 18: SEM micrographs of the Nanoparticles developed from LBPA particle. These shows that minimum average particle diameter is around 52.4nm.

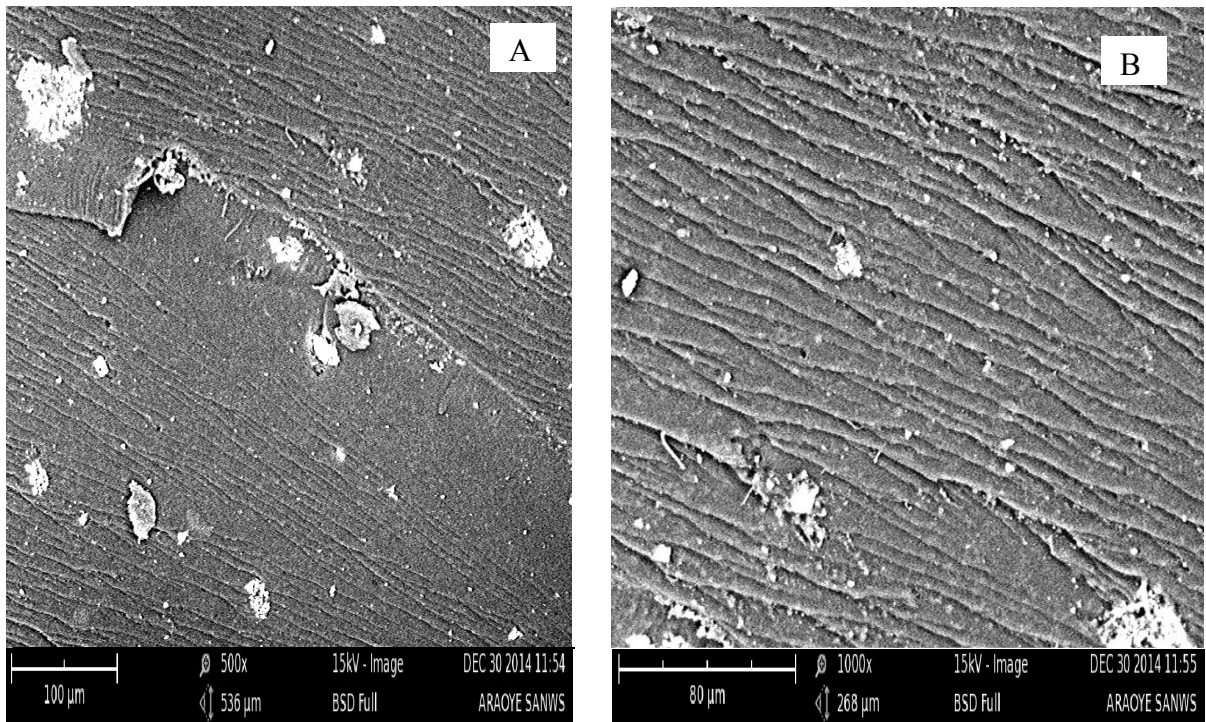


Figure 19: SEM micrographs of the polyester/Nano-LBPA composite exposed to natural weather for 90 days (at 3%LBPA) showing a rough surface (A) 500x (B) 1000x.

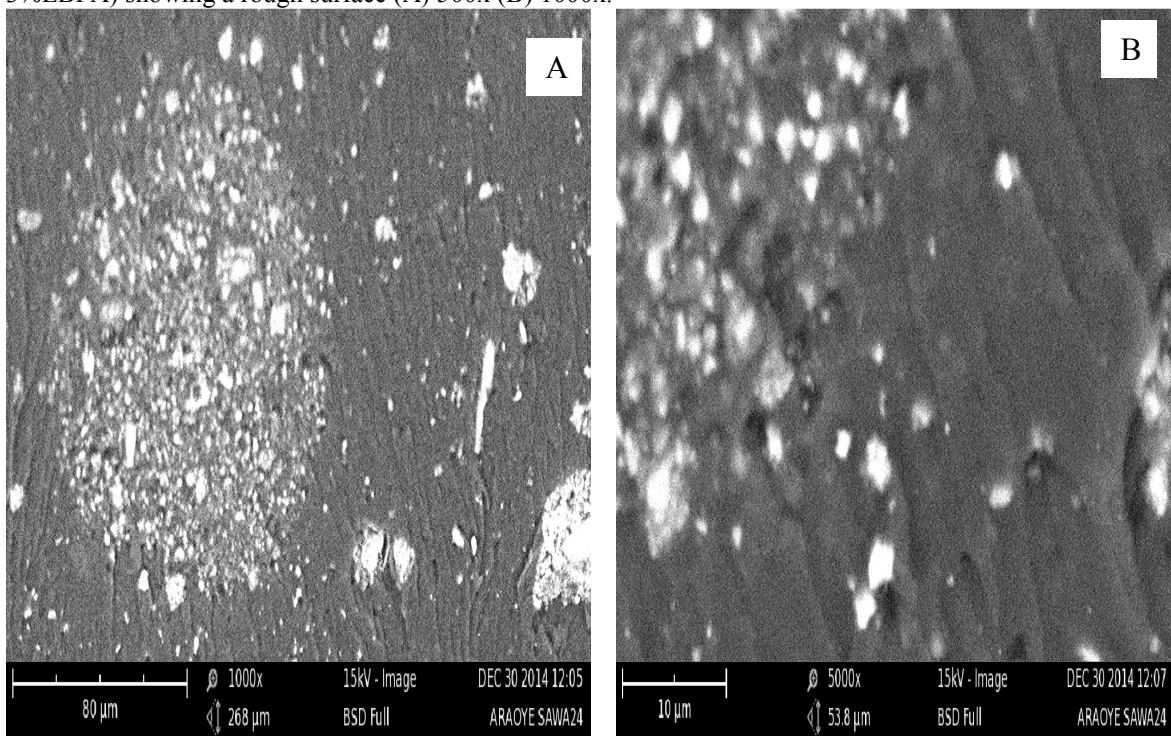


Figure 20: SEM micrographs of the polyester/Nano-LBPA composite after water absorption test for 24 hours, showing agglomerate of particles within the matrix phases (A) 1000x (B) 5000x.