



Studies on Some Quality Parameters of the Nigerian Polymer and Paper Bank Notes

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Authors' contributions

This work was carried out in collaboration between all authors. Author MBD designed the study, carried out the determination and analyses of mechanical properties of the notes and wrote the final manuscript. Authors AQI and HMA carried out the study on swelling indices in various solvents. Author OJE carried the study on microbial loads. All authors read and approved the final manuscript.

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ABSTRACT

There is no doubt that in Nigeria, the change to mis-using and counterfeiting of the paper bank notes have given cause for concern by the Central Bank of Nigeria (CBN), prompting the introduction of the polymer bank notes to address some of these problems. This research work investigates the physico-mechanical properties of samples of Nigerian polymer and paper bank notes of N5, N10, N20 and N50 denominations for quality parameters such as sizes, sorption rates, tear and tensile strengths, wet and dry rubfastness testing on standard Grey Scales ratings as well as microbial loads. The results showed that polymer notes have sizes of 131.0 x 72mm/0.7 on the average compared to 150.0 x 72mm/0.8 for paper for all the sample denominations. Tensile strength determinations on a Standard Organization of Nigeria (SON),s Stable Micro-System (SMS) Tensometer 5011 indicates $122.64\text{Nmm}^{-2}\pm 2$ mean for both polymer and paper while tear strength measurements on Elmendorf 2000 tear testing Machine showed a mean value of $6341.2\text{N}\pm 3.0$ for polymer as against $3223.8\text{N}\pm 5.0$ for paper. Rubfastness testings indicate that polymer notes have ratings of 4/5(wet condition) and 5 (dry condition) compared to 1(wet condition) and 2 (dry condition) for paper. Sorption rates (% Swelling Indices) in selected polar and non- solvents (liquids) were carried out as well as

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microbial loads and the results are reported in this paper. Generally, the results showed that polymer notes exhibit far superior physico- mechanical properties with very low coliform count compared to paper notes.

Keywords: Tear strength; tensile strength; rub fastness; sorption rates; microbial loads.

1. INTRODUCTION

Synthetic polymers have become an indispensable part of our everyday life since their introduction over 100 years ago. They are materials that generally display appreciable versatility in terms of utility and applications. Natural polymers such as cellulose, hemicellulose, lignin, lignocellulose, protein, etc are typical examples of complex compounds formed from lower molecular weight substances such as glucose, fructose, benzene derivatives and amino acids. Knowledge of the structure and utility of a number of natural polymers has, overtime, led to the synthesis of variously structured chemical materials designed to meet specific societal needs. These materials, classified as, "synthetic polymers/plastics" find practically unlimited applications globally at the present time. Typical areas of application include for example clothing, furniture, packaging, construction materials, automotive components, electrical and electronics, housing, food, agriculture and medicaments etc. [1-2].

Due to problems associated with the paper bank notes such as dampness, low resistance to tear stress, rubbing and staining, the polymer bank note was introduced for a variety of advantages which include; superior physical properties as tactile feel, tensile strength, tear resistance, recycle value, flexural endurance, resistance to staining and impervious to water compared to those of the paper notes. Apart from improving durability over paper, polymer bank notes was developed by countries like Australia, Singapore and Malaysia etc to prevent counterfeiting through incorporated security features, such as optically variable devices that are extremely difficult to reproduce [3]. One polymer that fits this application is polypropylene. Polypropylene is recognized as a robust, durable and light weight polymer and an ideal carrier for security documents for bank notes [4]. Polypropylene was first polymerized by Karl Rehn and Natta in March 1954 serving as a preliminary work for large scale synthesis from 1957 onwards. At first it was thought that it would be cheaper than polyethylene. An important concept in understanding the links between the structure of polypropylene and its properties is tacticity. The relative orientation of each methyl group (CH_3) relative to the other methyl groups on the neighboring polymer chain which has a strong effect on the finished polymer's ability to form crystals because each methyl group takes up space and constrains back bond bending [5-6].

Polypropylene is a linear hydrocarbon polymer containing little or no unsaturation. The significant influence of the methyl group is that it can lead to products of different tacticity, ranging from completely isotactic and syndiotactic structures to atactic molecules giving products with different physical properties. Isotactic polypropylene is a polymer of considerable commercial importance and several studies have been made on its crystalline structure and properties of the various solid phase. These studies have shown that the material can easily form a random phase and can be easily converted to crystalline form [7-8].

Most commercial polypropylene (density = 0.946g/cm^3) is isotactic and has an intermediate level of crystallinity between that of low density polyethylene (LDPE, 0.915g/cm^3) and high density polyethylene (HDPE, 1.35g/cm^3). It's young's modulus is also intermediate. Polypropylene is normally tough and flexible especially when co-polymerized with ethylene.

This allows polypropylene to be used as an engineering plastic, competing with materials such as ABS [6].

1.1 Advantages of Polymer Bank Notes

Polypropylene is translucent when uncoloured but is not readily made transparent as polystyrene, acrylic and certain other plastics. It is often opaque when coloured or pigmented. Polypropylene has good resistance to fatigue and is commonly recycled. A key environmental advantage is that polymer notes can be recycled while waste from paper notes could only be buried or burnt. Polymer notes no longer fit for use are granulated and then melted and blended into pellets. These pellets are the raw materials for recycling, a range of environmentally friendly products can be produced using polymer pellets including garden items such as compost bins, plumbing supplies as grease traps and house building items including brink and roof shingles [9-10].

The polymer substrate is more robust and resistant to damage from moisture, dirt, oils and house hold chemicals. This enhanced durability has resulted in a big reduction in the number of notes required and therefore printing costs for the notes. Since it is imperviousness to water, therefore longer life span of polymer note also means less waste compared to paper bank notes. Polymer bank notes have demonstrated exceptional resistance to soiling and crumpling that otherwise dramatically reduces the life span of bank notes in circulation. The polymer substrate has proven an extremely effective deterrent against counterfeiting due to its ability to incorporate sophisticated and effective security features at maximum cost and operational savings in both note issue and note handling and provide clean and secured bank notes to the public .It has also reduced the cost of replacing dirty notes and thereby free resources that could be used for other commitments [11]. Nigeria issued her first polymer bank note in 2007, starting with the ₦20.00 note and in 2009 introduced the ₦5, ₦10 and ₦50 notes [12-14].

1.2 Disadvantages of Polymer Bank Notes; Photo-degradation

Polymer bank notes are susceptible to photo degradation to different extent because of its highly crystalline nature and certain color additives present in them. Photo-degradation takes place as a result of exposure to uv- radiation from sun light, fluorescent tubes and arc lamps. The power to photodegrade increases as the wavelength of the incident radiation decreases, that is, as the energy of the quanta increases. Photo-degradation is widely recognized to proceed via free radical mechanism which results in discolouration, embrittlement and loss in mechanical properties [15]. The aim of this investigation is to compare the Nigeria's polymer and paper bank notes for parameters such as size variation, sorption rates (% swelling indices), tensile strength, tear strength and fastness to Rub as well as microbial loads in the light of handling environment in Nigeria and to use such parameters to offer advice to the Nigerian government and Central Bank of Nigeria (CBN) to issue out further polymer bank notes in the N100, N200, ₦500 and N1,000 denominations.

2. MATERIALS AND METHODS

2.1 Sample Collection

Sample specimens of polymer and paper bank notes in ₦5, ₦10, ₦20 and ₦50 denominations were collected from some Bureau de change houses and Commercial Banks in Jos, Plateau State and Lagos, Nigeria.

2.2 Apparatus/Reagents

Micrometer screw gauge, Standard Organization of Nigeria (SON) Automated Stable Micro System Tensometer 5011, Elmendorf 2000 Tear Tester, Veslic rub tester, Volumetric flasks, Scissors, Standard Grey Scales BS/3662/2 (SLF/3/&132), distilled water, ethanol, 0.01M HCl, 0.01M KOH, and Kerosene, ground nut oil, palm oil, and engine oil were locally obtained.

2.3 Determination of Sizes of the Notes

Samples sizes of the denominations of both polymer and paper notes were measured using a meter rule and the averaging three determinations in each case, while the thickness of the samples were determined using the micrometer screw gauge.

2.4 Determination of Tensile Strength and Elongation at Break

Test length of 80mm each were clamped to an automated (SON) Stable Micro System Tensometer 5011, one after the other and the readings of each sample was determined at break.

2.5 Determination of Tear Strength

The samples were cut to a size of 80mm by 50mm and clamped on an Elmendorf 2000 tear testing machine. A nick cut was initiated on the test pieces, leaving a standard initial untear width, in view of the fact that polymer tears more readily than paper once the process has been initiated. The scale release button was pressed and the scale reading taken. The tear strength is taken as the force per unit thickness of test pieces [16].

2.6 Determination of Rub Fastness [17-18]

2.6.1 Wet rub fastness

The sample sizes of 130mm by 70mm were measured and clamped on the appropriate number of felt pads and boiled to remove air bubbles. Pads were reduced to room temperature by decanting the hot water and replacing it with cold water. They were lightly squeezed (weight ~1.4g) and placed at the bottom of the shaft. Using a 500g loading, the samples were rubbed in the extended state for rubs circles of 50 each in a different location with new pads. The samples and felt pads were air dried and mounted on black card. The samples were polished to improve the nap before assessment. The samples were compared with the Grey scale for assessing the change in color. Visual changes in the samples appearance e.g. lighter, bluer, finish removed were compared with Grey Scale ratings. Transfer of color to the test pads were compared with a fresh one using the Grey scale for staining.

2.6.2 Dry rub fastness

The samples were cut to a size of 130mm by 70mm. A load was placed on the top giving a total of 1kg. The sample was clamped and stretching by 10% in order to achieve stability of rubbing. The sample was rubbed a number of times in different locations with new pads. The samples and pads were mounted on a black card. The nap was improved by brushing lightly.

The samples were compared with the Grey scale for assessing colour change and comments made on the visual changes in the samples appearance e.g. lighter, bluer, finish removed as before. The tested pads were compared with fresh pads, using the Grey scale for staining [18-19].

2.7 Determination of Sorption Rates (% swelling index)

Solvent sorption rates were determined by immersing clamped pre- weighed samples in a solvent/liquid at 30 mins intervals and allowed to drain completely for each run time and re-weighed to ascertain the change in weight at each interval. Solvents/liquids or solutions used include distilled water, ethanol, kerosene, dilute solutions of potassium hydroxide and hydrochloric acid, and vegetable oils such as palm and ground nut oils, and a hydrocarbon oil (engine oil). The % swelling index at each time interval was calculated using the formula;

$$\% \text{swelling index} = \frac{W_2 - W_1 \times 100}{W_1} \quad (1)$$

Where W_1 = Initial weigh of sample

W_2 = weight of sample after emersion at time interval.

2.8 Determination of Microbial Loads

This was determined by inserting different denomination of bank notes of polymer and paper (N5, N10, N20, N50) separately in sterile beakers containing 90ml of sterile distilled water which was left to stay for 24hours. 0.1ml of the solution containing different denomination was then inoculated in 100.0mm sterile petri-dish containing solidified Nutrient Ager (NA). The inoculated suspension was then septically spread with an L-shaped glass spreader and then incubated at 37°C for 24 hours. The visible colonies of micro organism were counted by the procedure of Egbere, 2008 [20].

3. RESULTS AND DISCUSSION

Table 1 shows the results of physical parameters and rubfastness ratings of the polymer and paper bank notes. Values for the paper notes are higher than those of polymer in terms of weights and sizes. The light weights and sizes of polymer notes (PP base material with density between 0.855 – 0.946 g/cm³) compared to paper notes (cellulose base material with density 1.5g/cm³) offers an advantage in the carrying capacity and portability over the paper notes. Rubfastness testings indicate that polymer notes have ratings of 4/5 (in wet condition) and 5 (in dry condition) compared to 1 (in wet condition) and 2 (in dry condition) for paper. This shows that polymer notes displayed far higher resistance to scratching than paper notes both in wet and dry conditions [18].

Figs. 1, 2 and 3 show the results of tensile strengths, % elongation at break and tear strength for polymer and paper notes respectively. The results indicate that polymer samples have mean tear strength of 6341.2N compared to that of paper samples at 3223.8N, with the polymer samples displaying far higher values of elongation at break which indicates the plastic and elastic (Hookean) behavior of polymer note over paper which exhibits brittle-fracture [10,21]. Tear strength is one mean quality parameter greatly displayed by the polymer substrate, about twice higher than the value for paper notes due to the tenacity differentials of the notes where PP substrate is essentially more crystalline (exists in monoclinic, trigonal and hexagonal shapes [22]). Tensile strength values are fairly similar for

both polymer and paper notes with the N20 polymer note sample displaying higher value due to the date of manufacture and the rate of circulation which were not taken into consideration in this present study.

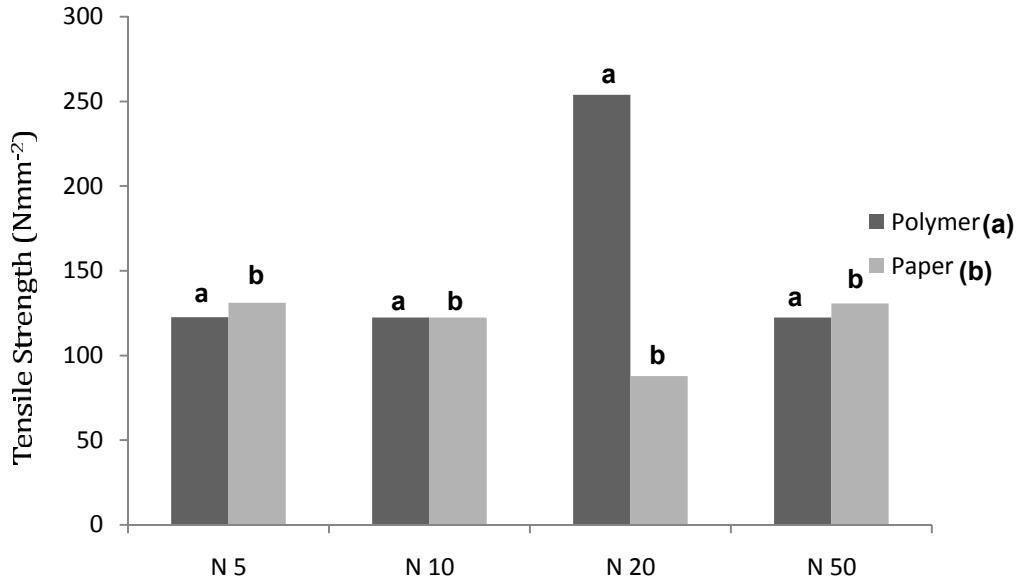


Fig. 1. Results of variations of Tensile Strength with polymer and paper bank notes denominations

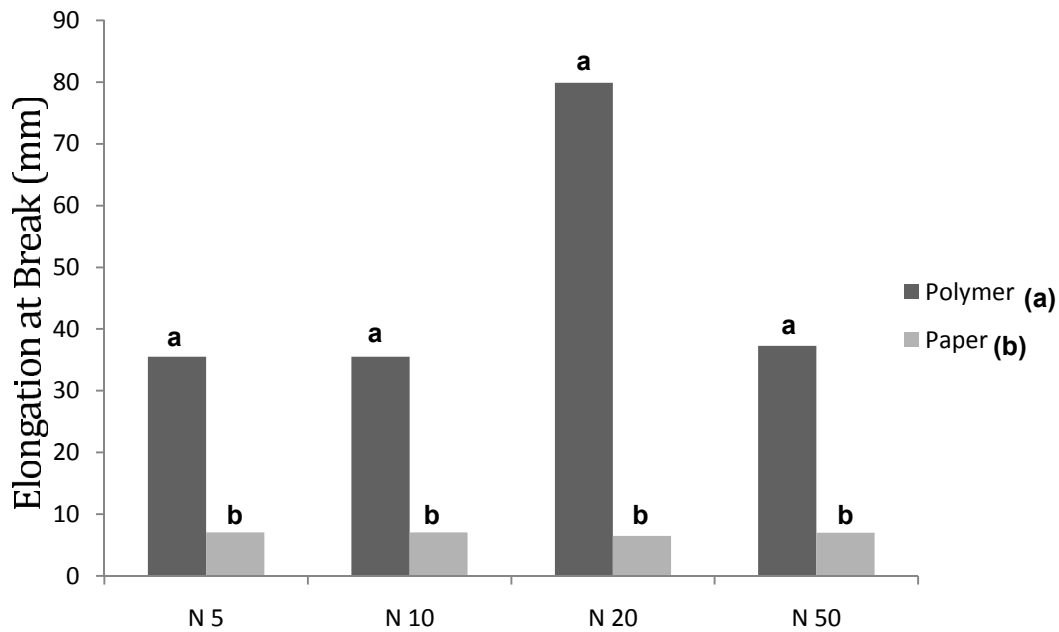


Fig. 2. Results of variations of Elongation at Break with polymer and paper bank notes denominations

Table 1. Results of physical parameters and rub fastness ratings of polymer and paper bank notes

Samples	Weight (g)		Thickness (mm)		Size (mm)		Rub Fastness (wet)		Rub Fastness (dry)	
	a	b	a	b	a	b	a	b	a	b
₦ 5	8.36	11.23	0.07±0.005	0.08±0.015	130.80x72.00	150.00x71.50	4/5±0.2	1/2±0.2	4/5±0.3	1/2±0.3
₦ 10	8.43	10.42	0.07±0.005	0.08±0.014	131.50x72.80	150.80x71.0	4/5±0.2	1/2±0.2	4/5±0.2	1/2±0.3
₦ 20	8.33	10.32	0.07±0.005	0.08±0.015	130.50x72.50	150.00x71.00	4/5±0.2	1/2±0.2	4/5±0.2	1/2±0.2
₦ 50	8.16	10.30	0.07±0.006	0.09±0.015	131.00x72.20	150.00x71.00	4/5±0.2	1/2±0.2	5±0.0	1/2±0.3

Grey Scale Ratings: 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Poor, 1 = Very Poor

Key: a = polymer bank notes, b = paper bank notes

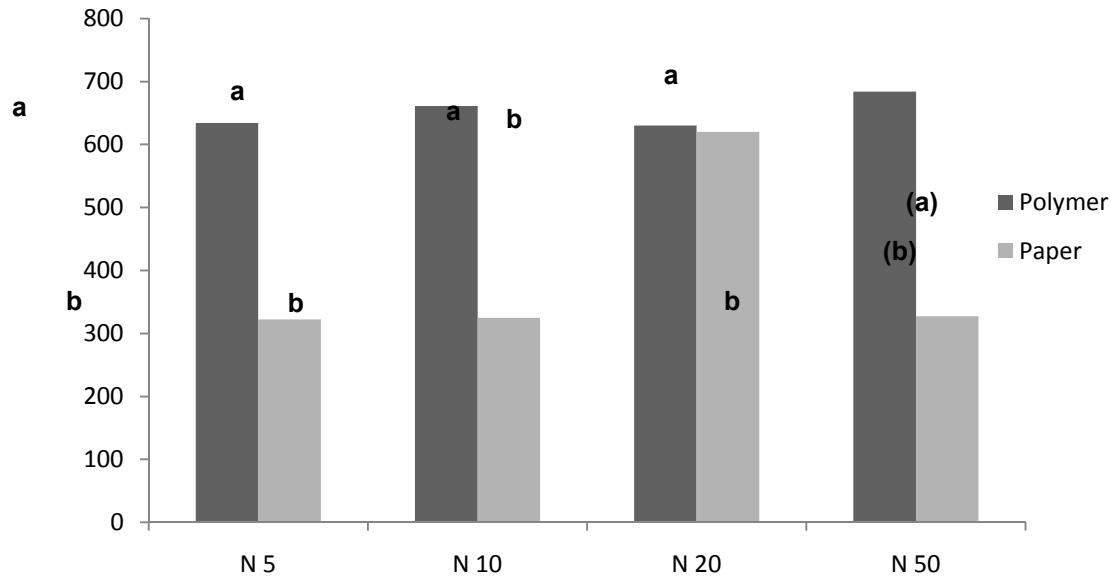


Fig. 3. Results of variations of Tear Strength with polymer and paper bank notes denominations

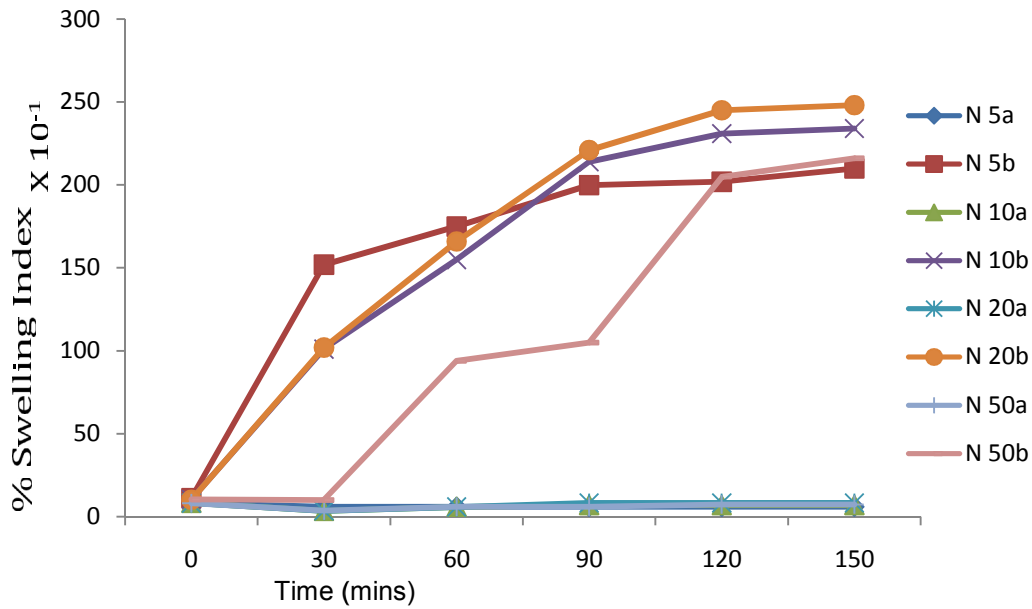


Fig. 4. Variations of % Swelling Index with time of immersion in distilled water
 Key: a = polymer bank notes, b = Paper bank notes

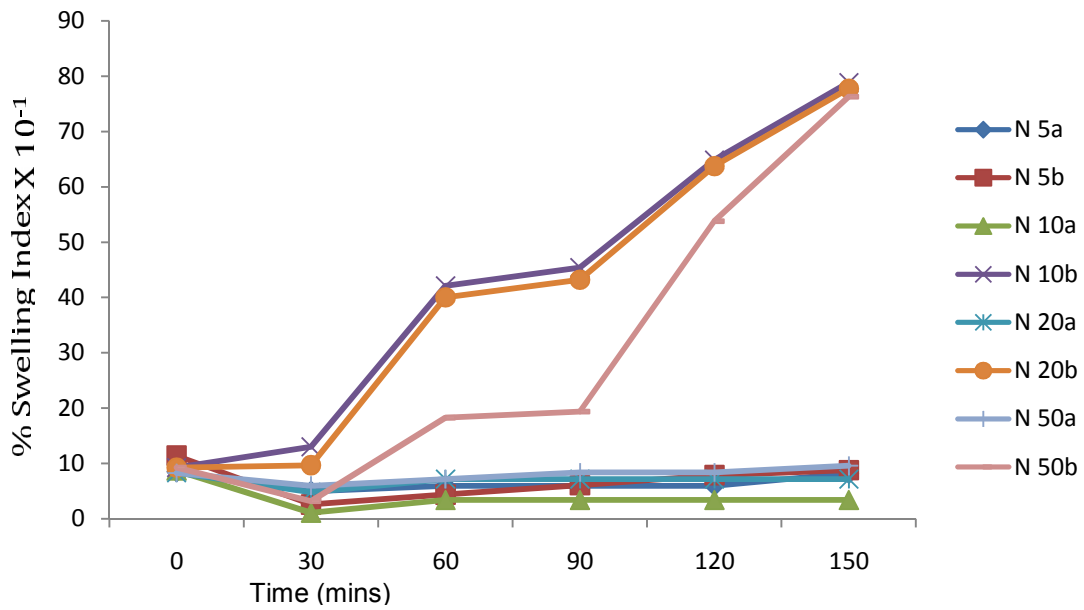


Fig. 5. Variations of % Swelling Index with time of immersion in ethanol
 Key: a = polymer bank notes, b = paper bank notes

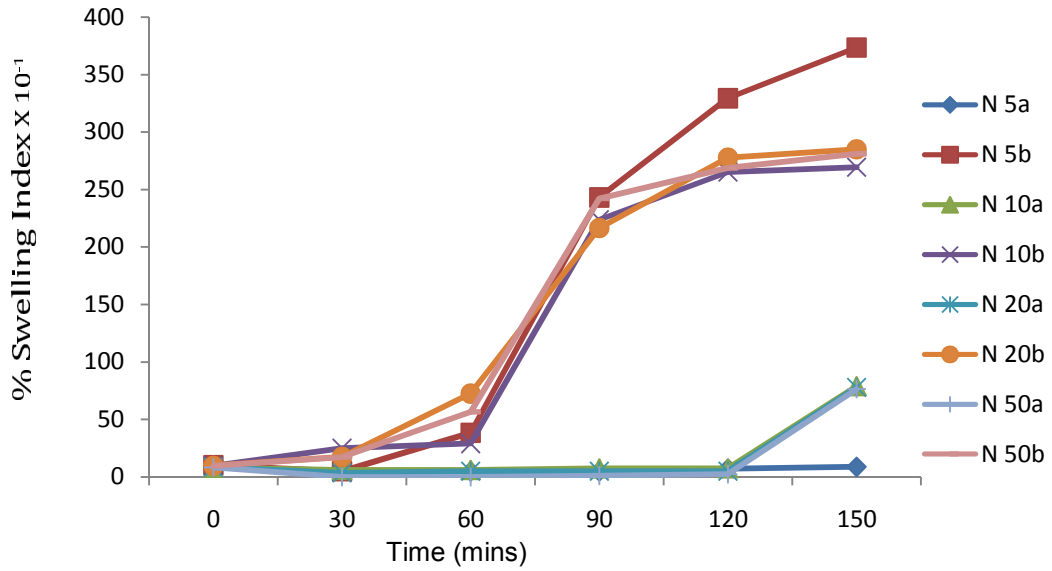


Fig. 6. Variations of % Swelling Index with time of immersion in 0.01M HCl
 Key: a = polymer bank notes, b = paper bank notes

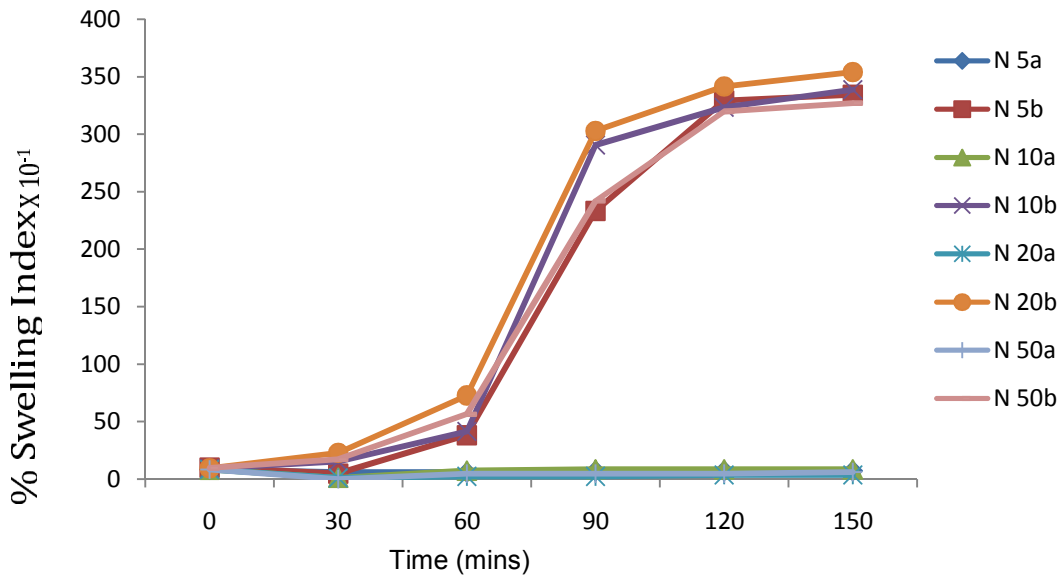


Fig. 7. Variations of % Swelling Index with time of immersion in 0.01M KOH
 Key: a = polymer bank notes, b = paper bank notes

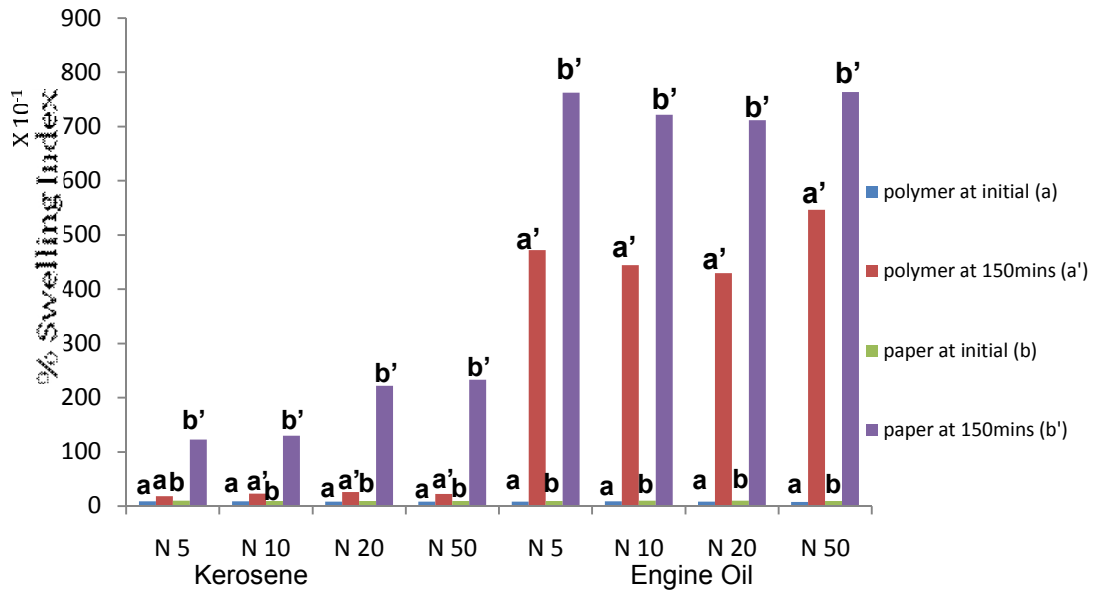


Fig. 8. Results of % swelling index with time of immersion in Kerosene and Engine Oil

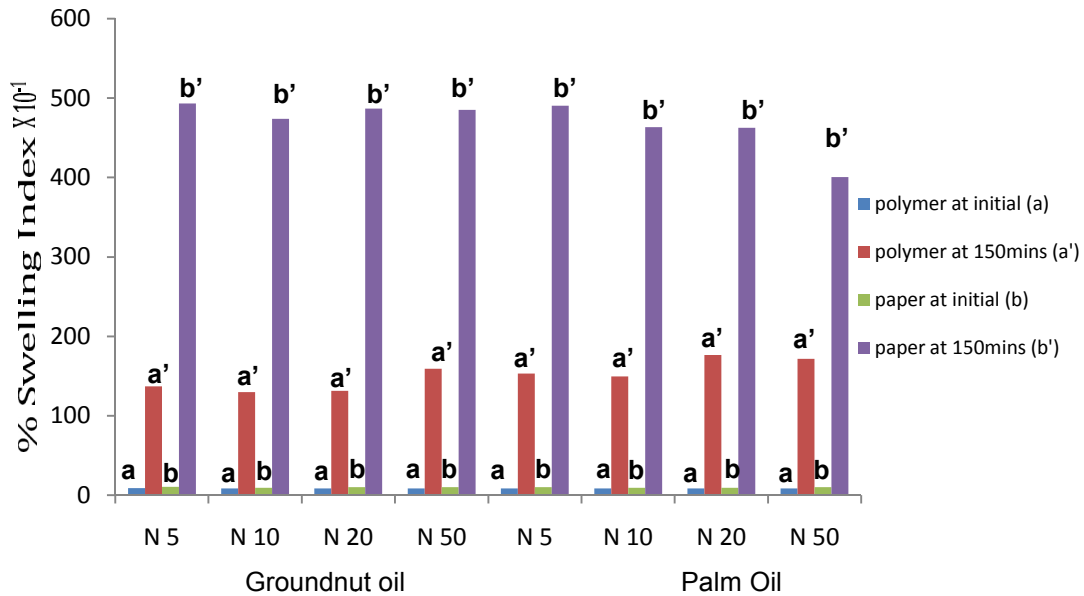


Fig. 9. Results of % Swelling Index with time of immersion in Groundnut Oil and Palm Oil

Figs. 4-9 compare variations of sorption rates (% swelling indices) with time of immersions in selected polar and non- solvents (liquids) for both polymer and paper bank notes; "a" denotes polymer and "b" denotes paper for all denominations. The results generally indicate that for all the liquids, polymer samples displayed far higher resistances to swelling than the

paper samples. This demonstrates that polymer-polymer interaction forces are far greater than the polymer-solvent forces which only results in little swelling indices compared to paper notes which have large % Swelling indices in all the solvents (liquids) considered. The lower the percentage solvent penetrating power the better the resistance [8]. The higher values for swelling indices in water and other polar solvents point to the fact that the paper base material which is cellulose substrate has high affinity for water and polar liquids compared to the PP, the base material for polymer note which is a hydrocarbon that is impervious to water. From the above considerations, it can be seen that cellulose can easily absorb moisture (water and other liquids) due to the presence of free OH side groups in its structure while PP exhibits high hydrocarbon nature with high degree of hydrophobicity [23]. Additionally, the overall structure of cellulose is of aggregated particles with extensive pores capable of holding relatively large amounts of water by capillarity [24]. Baker et al (1966) and Stone et al. (1998) have reported that the swelling of materials can be influenced by temperature, cross link type, density, amount, nature and type of compounding ingredients [25-26]. This description fits the behavior of the polymer bank notes in the various solvents employed. Similarly, Uzomah and Isa (2004) reported that sorption energetics of some solvents in thermally treated polypropylene (PP) films are affected by degree of crystallinity, texture of the PP and solvent polarity [27]. Figs. 4-7 display characteristics of polar solvents (liquids); water, ethanol, 0.01M HCl and 0.01M KOH where the paper notes exhibits far higher affinity for these liquids compared to the polymer notes as mentioned above. Figs. 8 and 9 compare the swelling indices of notes in hydrocarbon solvents (non-polar liquids); kerosene, motor (engine) oil, groundnut and palm oils that easily come in contact with notes handling in Nigeria. Again values demonstrate the concept of solubility parameters introduced by Hildebrand who was concerned with its application to mixtures of non-polar liquids. From thermodynamic point of view, solubility occurs when the free energy of mixing of solute and solvent [28].

$$\Delta G = \Delta H - T\Delta S \quad (2)$$

where ΔG = change in free Gibb's energy, ΔH = change in enthalpy, T = absolute temperature and ΔS = change in entropy.

The solubility parameters concept may aid in choosing solvents for a given system, but it does not tell anything about the condition of the polymer or resin in solution i.e. the intermolecular forces namely; dispersion forces, polar forces and hydrogen bonding forces which also constrain the disentanglement and extension of the polymer chains. A good solvent will tend to maximize (at relatively low polymer content) the viscosity of the solution at a given concentration. Polymer notes in kerosene and engine oil display this kind of interaction with comparatively low swelling indices though much higher in engine oil than kerosene (Fig. 8). Paper notes also display the same trend but with far higher values in both liquids. However, % swelling indices for paper in kerosene and engine oil are far higher than those of polymer notes within the 150mins immersion period. Fig. 9 however shows a different trend with the vegetable oils, values for swelling indices here are far greater and fairly constant for paper notes compare with the polymer notes. Polymer notes swell more in vegetable oils compared to the values for kerosene but show similar values to those of engine oil. Comparing and contrasting the values for the vegetable oils and the engine oil show that these liquids merely become adsorbed on the surface of the notes and not actually due to absorption [29].

Table 2 shows the results of microbial loads which indicates that paper notes exhibits 2-6 times coliform count loads more than the polymer notes. This can be attributed to the

cellulose base material of paper which is more susceptible to microbial attack as reported by Awodi et al. [30-31]; Bassavuvapappa and Suresh.

Table 2. Results of microbial loads of polymer and paper notes (colony count at 37°C)

Samples	Polymer(cfu/g) x(10 ²)	Paper (cfu/g) x(10 ²)
₦5	4.00	9.00
₦10	1.70	11.00
₦20	5.30	12.00
₦50	2.70	12.00

4. CONCLUSION

Comparison of the results obtained show that polymer note is far superior than paper note in terms of physico-mechanical properties such as tear and tensile strengths, sorption rates (% swelling indices) and resistance to scratching and staining as well as low microbial loading in the light of handling habits of many Nigerians. Due to the challenges posed by photo-degradation of the polymer notes, we would like to strongly recommend to the Federal Government of Nigeria and CBN the utilization of both preventive and arrestive photo stabilizers. Polymer bank notes prone to uv-degradation can be stabilized by incorporation of special additives commonly known as uv-absorbers, for example carbon black, (1-5%), benzophenone and its derivatives, phenyl salicylates and benzotriazoles which also gives protection against uv-degradation and also the use of Ba/ Cd soaps as heat stabilizers [21].

5. RECOMMENDATION

It is strongly recommended that more work should be done on polymer bank notes to improve its resistance to photo-degradation. However, we suggest further that in future, the Central Bank of Nigeria and the Nigerian Security Printing and Minting Company should convert other denominations of the Nigerian bank notes still in paper to polymer in the light of the note handling behavior of most Nigerians. In the meantime, the Federal Government should introduce legislations and enforcement of same in the handling of bank notes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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