Mechanical Properties of Potato- Starch Linear Low Density Polyethylene Blend

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ABSTRACT: The mechanical properties of potato-starch filled LLDPE such as Young's Modulus, tensile strength and elongation at break were studied. Apart from the Young's Modulus, the tensile strength and elongation at break reduced with increased starch content. This is attributed to poor adhesion between starch and the polymer matrix. The mechanical properties however, conform to Kerner's and Nielson's models with very minimal deviations.
Keywords: Young's Modulus, elongation at break, Kerner's and Nielson's Composite Models, LLDPE.

INTRODUCTION

The search for biodegradable thermoplastics for obvious environmental advantages indicated that starch-filled thermoplastics are economically more viable (Whistler, 1984; Doane, 1992). They however suffer from decreased mechanical properties. This problem is attributed to the hydrophilicity of starch, which could cause an increase in water absorption leading to decrease in mechanical properties, such as tensile strength and elongation (Griffin, 1974, 1990; Evangelista *et al.*, 1991). Several works have been carried out on the effect of different sources of starch as filler for different thermoplastics (Griffin, 1974, 1990; Seidenstucker and Fritz, 1998; Bikiaris *et al.*, 1999; Ke *et al.*, 2002). The effect of starch particle size on mechanical properties showed that smaller particle size gave better results; this was attributed to a non-uniform distribution of internal stress and strain associated with the large particle size when compared to filler with smaller particle size (Wang *et al.*, 2003). Many workers have extended the use of starch as filler to completely biodegradable polymers for the same reason of economics (Wang *et al.*, 2003). Ke and Sun (2001), reported that PLA (poly lactic acid) filled with starch did not show different thermal behaviour by the presence of starch. But the tensile strength and elongation of the composite decreased as starch content increased, due to weak adhesion forces between PLA and starch phases. The adhesion forces are formed by polar interactions due to hydrogen bonding between carboxyl groups in PLA and hydroxyl groups in starch (Ke and Sun, 2001; Ke *et al.*, 2002). The present work is an attempt to characterise the mechanical properties of potato starch filled LLDPE blend with some known composite models.

MATERIALS AND METHODS

Sample procurement

Potato tubers used in this study were purchased in Zaria.

Reagents used

All reagents and chemicals used in the study were of analytical grade.

Extraction of starch

The potato tubers were chopped into small pieces and then wet-milled. The suspension was filtered with a very fine sieve; the filtrate was allowed to stand for 24hrs in the presence of 1% sodium thiosulphate to prevent fermentation. Pure starch obtained by decantation was dried at 50^0C for 48hrs. Particle size of the starch granules was determined with the help of a binocular microscope.

The starch granules have particle size ranging from 3 – 100µm. The moisture content of the starch was found to be 13% while the decomposition temperature and refractive index were 235^0C and 5.3 respectively. Powdered Linear low-density polyethylene (LLDPE) was obtained from the College of Chemical and Leather Technology (CHELTECH) Samaru, Zaria and had peak melting temperature of 130^0C.

Sample Preparation

The potato starch granule was thoroughly mixed with the low linear density polyethylene (LLDPE) also in granulated form and melt-blended at 150^0C. 25g of the starch granule were thoroughly mixed with 25g of the LLDPE in three different containers. Silicon oil and aluminum foil sheet were used as processing aids. Flat plate shaped composites were obtained using 200mm thick aluminum sheet moulds filled with LLDPE/starch mixture. The composites were made by compression molding using two steel plates in a Kao Tich Go Tech compression machine in the polymer laboratory of the National Research Institute for Chemical Technology (NARICT). The moulded samples were cut into rectangular shapes (5.5mm by 2.5mm) and used for all the tests. The composites were designated as PS/PE composite and labelled.

Determination of Tensile Properties

Samples for tensile measurements were conditioned at room temperature and 30±2% relative humidity (RH) for 24 hours before testing. Tensile measurements of samples were carried out on a stelometer (Tensile Tester) in triplicates according to ASTM D638.

RESULTS AND DISCUSSION

Effect of Starch Loading

It can be seen in fig.1 that the incorporation of potato starch into LLDPE led to an increase in the modulus of the composites. Several literature sources have also made the same observations (Willet, 1994; Schroeter and Hobelsberger 1992; Nawang *et* al., 2001). They reported increase in modulus of corn and potato starch-filled LDPE and sago starch-filled LLDPE matrixes respectively. It was suggested that this had to do with higher stiffness of the starch granules over the flexible polymer matrix in which they were dispersed (Prencn, 1984; Trimnell *et al.*, 1993; Willett, 1994; Arvnitoyannus *et al.*, 1997). This stiffening effect of starch is due to hydrogen bonding in its sub-macromolecular structure which is absent in LLDPE. The effect of starch volume fraction on the modulus fitted Kerner's model (Arvnitoyannus *et al.*, 1997) depicted in Equation (1), although with larger deviation as the starch content was increased. This deviation is ascribed to the presence of the more irregularly – shaped starch granules and the variability in granule size (Mascia, 1982). Mechanical properties of composites depend not only on filler volume but also particle size, shape and the degree of adhesion of filler to the matrix (Willett, 1994).

$$E_C = E_O(1 + (17V - V)(15(1 - v)/(8 - 10v) \quad (1)$$

Where E_c and E_o represent the modulus of the composite and the matrix while V and v stand for the filler volume fraction and the poisson's ratio of the matrix respectively. The subscripts C and O represent the composite and the matrix respectively. A value of 0.5 was used for the Poisson's ratio.

Yield Stress

The yield stress indicates a measure of the strength of a polymeric material at the point of deviation from Hook's law (the yield point). The yield strength increases with increase in filler (starch) content because the starch carries higher loads than the matrix (Mascia, 1982).

Fig.2 shows the effect of starch volume fraction on the relative yield stress of the composites. It was plotted according to equation (2):

$$\sigma_{yc} = \sigma_{yo}(1 - 1.21\, ø^{2/3}) \quad (2)$$

Where σ_{yc} and σ_{y0} are the yield stress of the composite and the matrix respectively, and ø is the filler volume fraction (Nicolais and Narkis, 1971).

The result indicated a large deviation of yield stress from theory predicted. This was attributed to filler geometry as a consequence of the irregularly-shaped starch particles having different distribution of granule size which will not permit close packing of the granules (Mascia, 1982). Therefore the stress concentration effect will also deviate from –1.21 as predicted by theory.

Tensile Strength

The effect of starch volume fraction on the relative strength of the composites is shown in fig.4 according to Nielson model (Nielsen, 1966).

$$\sigma_c = \sigma_o\left(1 - 1.21\varphi^{2/3}\right) \quad (3)$$

Where σ_c and σ_o are the tensile strengths of the composite and the matrix respectively, and the φ is the starch volume fraction.

There is a greater correlation between theory and our result. Theory predicted that the tensile strength decreases as the filler concentration increases. Earlier work in the same theme suggested that the incompatibility between the hydrophilic starch and the hydrophobic polymer was the main reason (Hwan-Man, 2002). Adhesion rather than particle size is believed to influence tensile strength more (Willet, 1994).

Elongation at Break

Theoretical effect of filler volume on the relative elongation at break of the composite was calculated according to Nielsen's equation (4) and shown in Fig.5.

$$\varepsilon_c = \varepsilon_o \left(1 - \varphi^{1/3}\right) \qquad (4)$$

The elongation at break decreases with increase in starch volume just as predicted by the model. Elongation at break depends on the interfacial adhesion between the components of the composite, absence of this and also the stiffening effect contributed by the starch resulted in the reduction of the elongation at break with increase in starch volume (Chandra and Rustgi, 1997). It is due to the poor interaction between the components stemming from the hydrophobicity of the starch in hydrophilic environment. Furthermore, there was aggregation of the granules leading to stress concentration points.

CONCLUSION

The mechanical properties of LLDPE filled with potato starch resulted in increase in modulus and decrease in tensile strength and extension at break all with increase in filler volume. This is in agreement with Nielson models with minimal deviations.

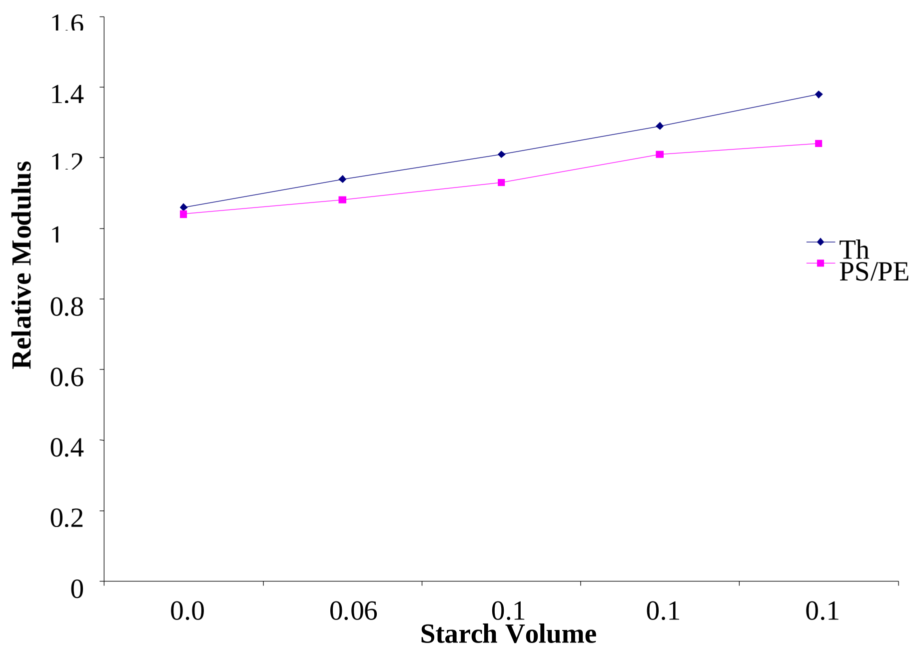

Fig.1: Effect of Starch volume fraction on relative modulus of potato starch LLDPE Composites

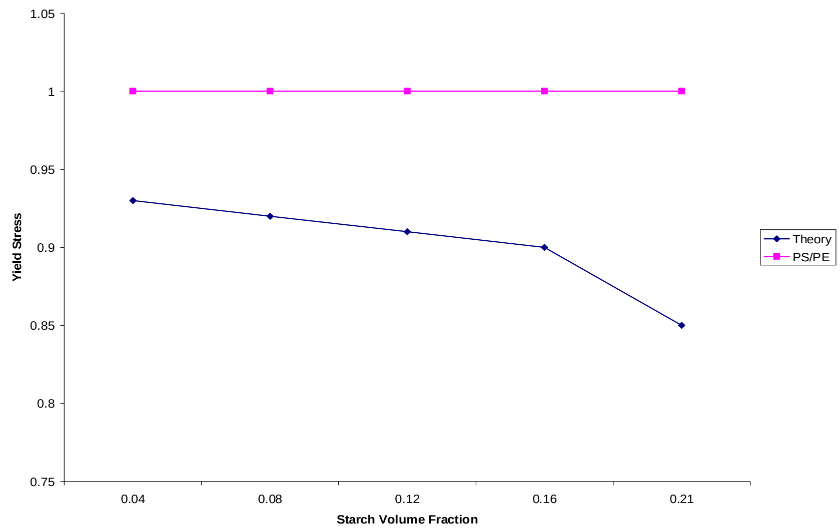

Fig.2: Effect of Starch volume fraction on relative yield stress of potato starch LLDPE composites

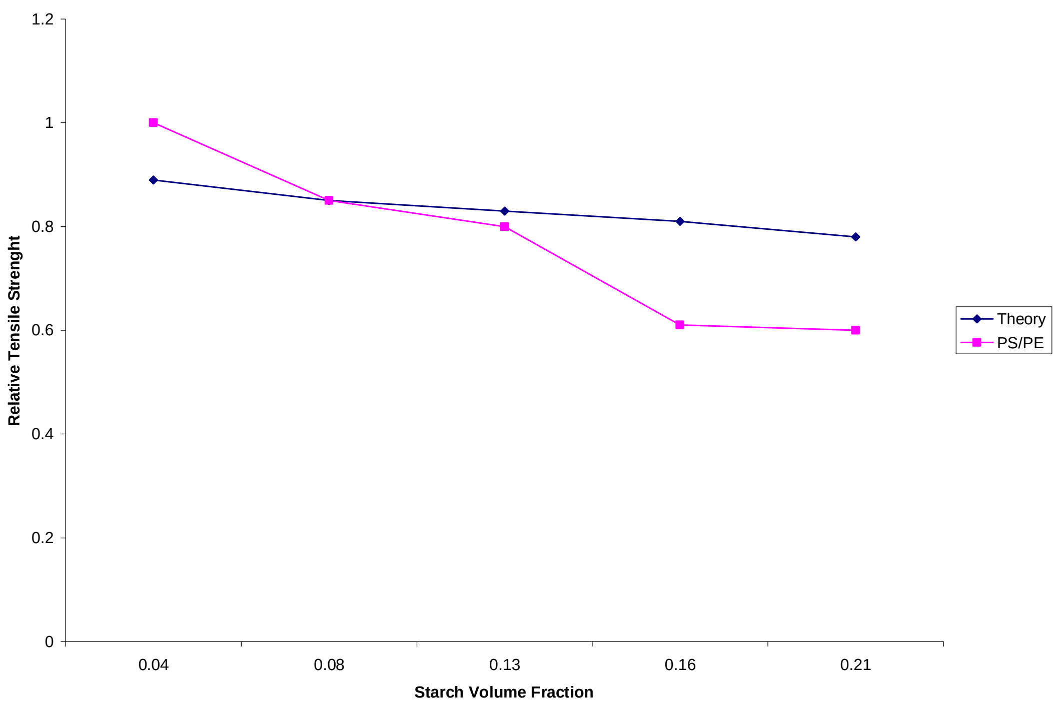

Fig. 4: Effect of Starch volume fraction on relative tensile strength of potato starch LLDPE Composites

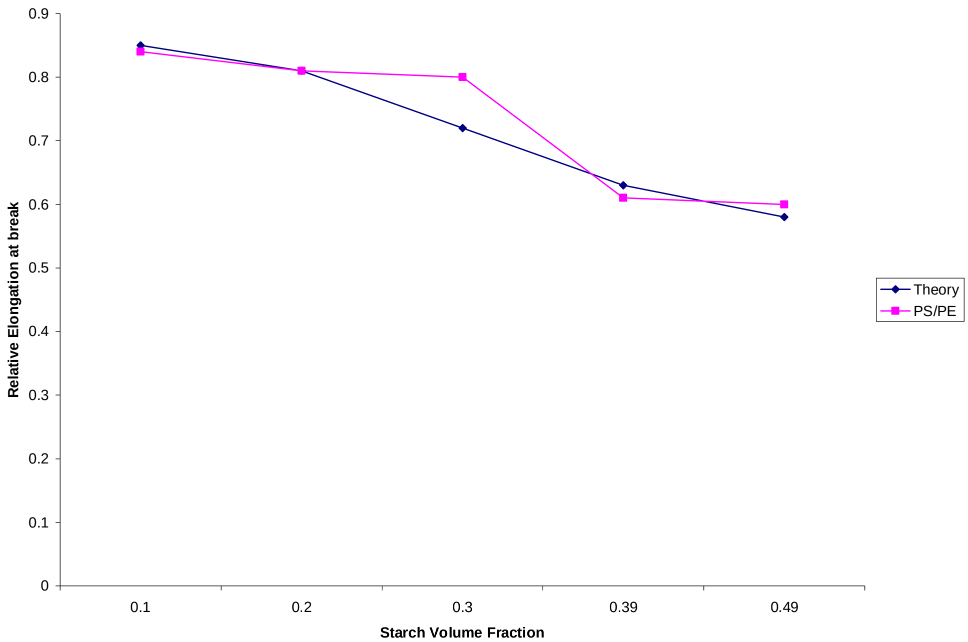

Fig. 5: Effect of Starch volume fraction on relative elongation at break of potato starch LLDPE Composites

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