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Effect of Composition Variation on the Tensile Strength of Polylactic Acid Reinforced with Natural Polymers for Biodegradable Biomedical Implants

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Authors' contributions

This work was carried out in collaboration between both authors. Author ONG designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author SDW managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: This research focuses on developing a blend of natural polymers suitable for biomedical implants with standard mechanical (tensile) properties, compatible and consumable with human body

Study Design: This research developed a polymer composite from a blend of the three natural polymer materials with different compositions that can adequately replace non-biodegradable implants.

Place and Duration of Study: The research was conducted at the department of industrial and production engineering and department of metallurgy and material engineering federal university of technology akure Nigeria between 2017 and 2018.

Methodology: Such PLA was blended with starch and chitosan which are the two most abundant

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natural polymers using compression molding machine. The mechanical (tensile) property test carried out which give information on the strength and stiffness of the composite using the ASTM D3039.also the effect of composition variation of each of the constituent polymer was analysed using multiple regression analysis.
Results: The results shows similarity with the mechanical (tensile) properties of cortical bone which is the major bone in the human body that is susceptible to fracture. The result of the regression analysis revealed a negative 43.129 effect of PLA on the tensile stress; positive 10.43 effect of starch on tensile stress; negative 0.596 combine effect PLA and starch on the tensile and the effect of chitosan we have a NA value which implies that the coefficient is not quantifiable.
Conclusion: Combining PLA and starch with chitosan to obtain biodegradable implant materials represents.

Keywords: Biodegradable; Chitosan; composite; compression molding; poly-lactic acid; starch.

1. INTRODUCTION

A biomaterial is defined as any natural or synthetic substance engineered to interact with biological systems in order to direct medical treatment [1]. The increase in need for biomedical implants over the years has equally spurred an increase in research in the area of materials that can be safely introduced into the body system without causing harm.

In recent development, the major challenge affecting the commercialization of synthetic polymers implant is cost [2]. To curb this, the relatively abundant natural polymer like starch, a source of PLA [3] is being considered in bone tissue engineering [4] to reduce the dependence on synthetic polymers obtained from fossil fuel. In the marine environment, chitin is confirmed to be the second most abundant biopolymer in nature after cellulose [5].Chitin forms the main exoskeletons of arthropods such as crustaceans and it has been extracted from crab, crayfish, periwinkle and shrimp [6].

The use of natural biopolymers in implant has been proposed by several authors [7,8,9,10]. The major constraint is the combination of natural polymers that will give the mechanical strength of tissue repair [11,12]. The mechanical and degradation properties of the potential materials for bone implant is of major concern to researchers in engineering and medicine. The general criteria for selecting a polymer for use as an orthopaedic implant are its ability to combine mechanical properties with degradation time to the needs of the application such that sufficient strength remains until the bone is healed. As the cost of synthetic polymer is high which result in expensive orthopaedic implant, it is of much importance to consider the natural source of polymer as an alternative. Hence the consideration of Using chitin and starch in these study to produce bio-implant.

The major concern in this study are the mechanical properties of the material and consumability of the material by the body. This informed the choice of the material; poly lactic acid, chitin and starch are all consumables and the effect on the body is minimal on the long-run. Also the need for affordable biomedical implants is one of the basis of the research. The process of making implants affordable can easily be achieved if the base materials can be naturally obtained.

2. MATERIALS AND METHODS

2.1 Materials

The material selection for this research is governed by the desire to shift focus from synthetic polymers to natural polymers for the synthesis of biomedical materials. The natural polymers are readily available and easily produced, therefore, optimising their properties to those suitable for biomedical implants will greatly reduce the cost of biomedical implants. The polymers to be used for this research include chitin which is extracted from crab bones, starch which is produced from various foods and PLA which can be produced from corn starch, cassava roots. Starch has adhesive properties which can make it a suitable binder for the composite. Also, the combination of chitin and calcium carbonate produces a tougher and less brittle structure which is a useful property for the blend.

2.2 Composition Variation

The PLA will range from 92% to 98% of the composition, starch and chitosan will range from

2% to 8%. The PLA serves as the matrix, the chitosan is a reinforcement and the starch is a binder. The composition variation for research is shown in Table 1.

2.3 Compression Molding Process

The essence of choosing compression molding (Fig. 1) is because it is a suitable method for producing high strength plastic and polymer materials. It is a closed molding process with high pressure application.

2.4 Experimental Design for the Compression Molding Process

The composite will be produced by compression molding, the compression molding machine has a variety of control options that determine the final properties of the molded sample. The parameters that need to be controlled include Mould Temperature, Holding Pressure and Holding time. The temperature used for the mould was 750C and the mould pressure used was 1.5 metric tons with a holding time of 15mins. The composition variation was based on after previous experiment from [13] and pre - trial experiment during this research the percentages of chitin and starch was varied between 8% to 0% at interval of plus or minus 2%.

Table 1. Percentage composition for the experiment

S/N	Percentage composition		
	PLA (%)	Starch (%)	Chitosan (%)
1	92	8	0
2	92	6	2
3	92	4	4
4	92	2	6
5	92	0	8
6	94	6	0
7	94	4	2
8	94	2	4
9	94	0	6
10	96	2	2
11	96	4	0
12	96	0	4
13	98	2	0
14	98	1	1
15	98	0	2

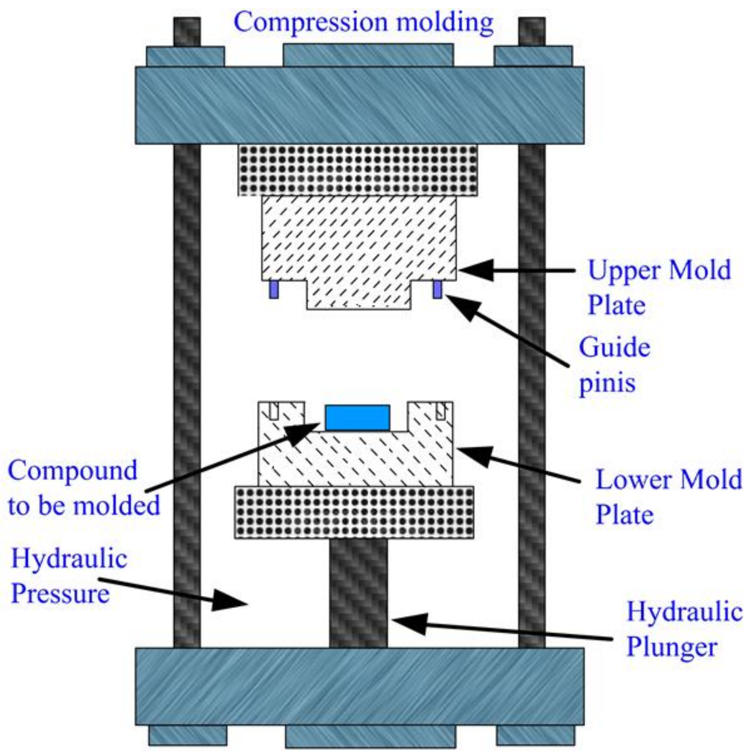

Fig. 1. Compression molding machine

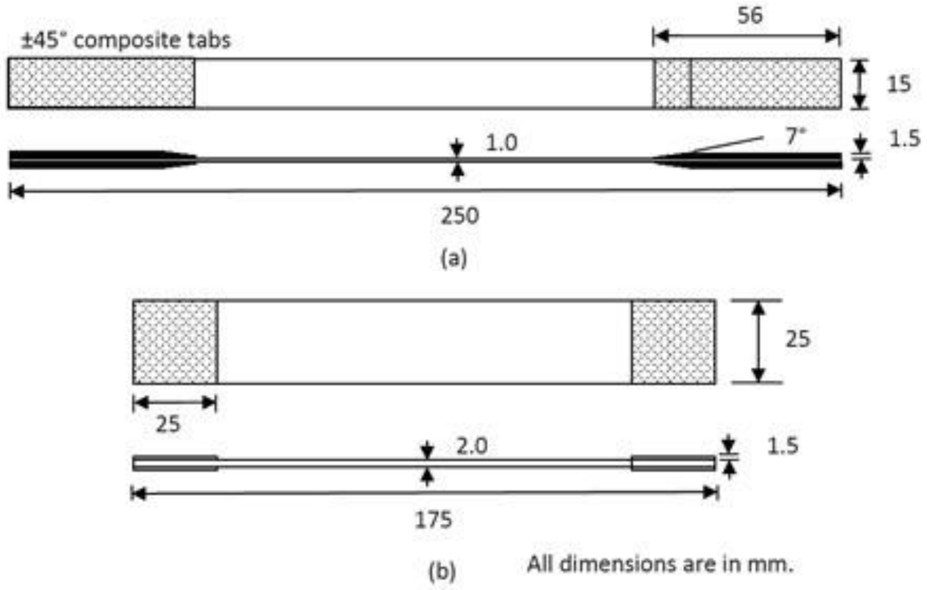

Fig. 2. Polymer composite specimen for tensile test [14] www.astm.org

2.5 Mechanical Property Test

The mechanical (tensile) properties of the samples were tested. Using American standard for material test, the tensile, test method ASTM D3039 is selected with standard dimension. The test method is used for reinforced or unreinforced materials including high modulus composites and for materials that do not fail within the limits. This is shown in Fig. 2.

3. RESULTS AND DISCUSSION

The results from the various tensile tests conducted on the samples show some important properties about the behavior of the composite under different kinds of load. The results of the tests comparing them to the equivalent properties of packaging materials are discussed in the following sections. The maximum tensile stress the withstood by a single sample is 16.09328MPa (Fig. 3) which was gotten form the sample with 98% PLA and 2% Chitosan when compared with the control sample of 100% PLA with tensile strength of 25.47186 MPa (Table 2). This Tensile strength is close to the strength of the neat PLA used showing that a further research into a favorable composition or with a compatibiliser will further increase the strength of the composite. The graph of strain Energy to strain at break point shows significant similarities with the graphs that compare the tensile stress which validates the tensile stress values deduced from the experiment. The tensile properties of the polymer composite are shown in Tables 2 and 3 respectively.

From the Fig. 3 it can see the composition with PLA: STARCH ratio of 98:2 having a tensile strength of 16Mpa and a tensile modulus of 758.401 MPa and a percentage elongation of 2.1%, this indicates that the composite is more flexible and still maintains its strength to a great extent compared to the neat PLA having a tensile modulus of 986.9 MPa. And a percentage elongation of 2.5%. This gives this composite a fairly large amount of applications as a biomedical material ([15,16]) such as cancellous bone scaffold [17] and other tissue repairs.

3.1 Statistical Analysis with Multiple Regression

The data was analyse using multiple regression analysis to understand the significant interactions between the variables and its corresponding effect on the Tensile strength. The result is presented in Table 3 and equation 1.

lm (formula = MAX. TENSILE. STRESS. Mpa. ~ PLA + STARCH + CHITIN + PLA * CHITIN + STARCH * PLA + STARCH * CHITIN)

Multiple R-squared: 0.6948, Adjusted R-squared: 0.5252

Table 2. Tensile properties of all the samples

S/N	Percentage composition			Max tensile stress (MPa)	Tensile strain	Tensile modulus (MPa)	Percentage elongation
	PLA	Starch	Chitosan				
1	92	8	0	12.54511	0.01491	841.389	1.491
2	92	6	2	5.57529	0.01319	422.6907	1.319
3	92	4	4	9.94309	0.01319	753.8355	1.319
4	92	2	6	4.75518	0.01032	460.7733	1.032
5	92	0	8	3.13441	0.01147	273.2703	1.147
6	94	6	0	11.03011	0.01376	801.6068	1.376
7	94	4	2	4.39615	0.01835	239.5722	1.835
8	94	2	4	4.08169	0.01032	395.5126	1.032
9	94	0	6	6.12882	0.01319	464.6566	1.319
10	96	2	2	5.98291	0.01835	326.0441	1.835
11	96	4	0	7.46651	0.01491	500.772	1.491
12	96	0	4	2.34632	0.00803	292.1943	0.803
13	98	2	0	13.61428	0.01319	1032.167	1.319
14	98	1	1	10.6949	0.01319	810.834	1.319
15	98	0	2	16.09328	0.02122	758.4015	2.122
16	100	0	0	25.47186	0.02581	986.8989	2.581

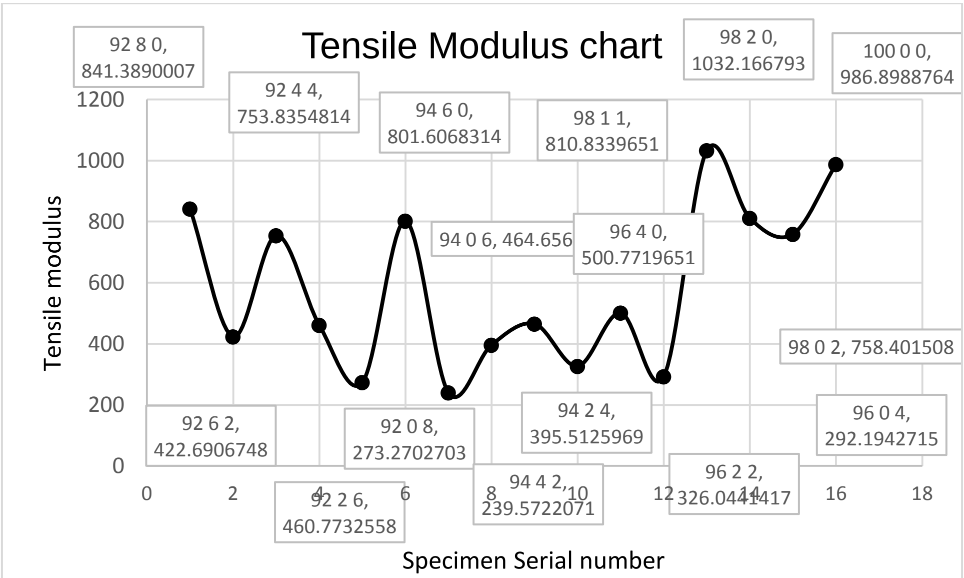

Fig. 3. Graph showing the tensile modulus of all the samples

Table 3. Tensile stress regression analysis output

Coefficients: (1 Not Defined Because of Singularities)		
	Estimate	**Pr(>|T|)**
(Intercept)	4335.9879	0.0578
PLA	-43.1285	0.0585
Starch	10.4308	0.6164
Chitin	Na	Na
PLA: Chitin	-0.4941	0.0508
PLA: Starch	-0.5965	0.0237*
Starch: Chitin	-0.1291	0.4591

Fitted regression equation:

μ_(y|x)=4335.988-43.129P×PLA+10.43×STARCH+NA×CHITOSAN 0.494×PLA×CHITOSAN-O.596×PLA×STARCH-0.129×STARCH×CHITOSAN (1)

The analysis shows the effect of PLA on the tensile strength dependent on CHITOSAN and STARCH. The analysis output shows the p-value for PLA: CHITOSAN and STARCH: CHITOSAN which are .0508 and .0459, which implies that this interaction is not statistically significant, therefore it is not include it in the model. While for PLA: STARCH there is a statistically significant interaction that as occur between this two variables.

Therefore the fitted regression model would be reduced to;

μ_(y|x)=4335.988-43.129×PLA+10.43×STARCH+NA×CHITOSAN-O.596×PLA×STARCH (2)

The above equation 2 shows a negative 43.129 effect of PLA on the TENSILE STRESS adjusting or controlling for STARCH and CHITOSAN. The estimated effect of STARCH on TENSILE STRESS to be 10.43 increase, adjusting PLA and CHITOSAN. Also the estimated significant interaction effect between PLA and STARCH to be negative .596. The effect of CHITOSAN result in NA value which implies that the coefficient is not quantifiable, and it could be due to exact collinearity. Also, the R-squared value is 0.6948 which implies that approximately 69% of the variation in maximum tensile stress can be explained by the experiment and the model derivable from the experiment. The conclusion of the results is that for the tensile strength, the percentage composition of starch has a significant effect on the maximum tensile stress the material can withstand than chitosan this is justified as PLA and starch are related as they can be source I.e. from corn starch so the bonding effect and mixing will be more. The chitosan will just form scattered particles in the composite mix.

4. CONCLUSION

This paper has shown the effect on composition variation on the tensile property of the composite and also propose the use of the composite as a replacement for synthetic in tissue repair and replacement. Poly lactic acid - Starch – chitin composite was fabricated and the tensile properties analysed and compared with tissue material tensile properties from literature. The finding shows that this material can be used for a number of replacement and repair implant material. Combining PLA and starch with chitosan to obtain biodegradable implant materials represents good alternative means to reduce use of synthetic polymer or metallic materials. The blending of these polymers in adequate proportions with the incorporation of some compatibilisers on further research will yield high performance material which can meet several biomedical requirements. The use of this composite which is obtained from natural compounds will reduce the use of non-biodegradable implants on the body. Consequently, it will cause a paradigm shift from the heavy dependence on non-biodegradable metallic materials to lower cost natural polymers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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