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Evaluation of uncertainty of measurement for cellulosic fiber and isotactic polypropylene composites subjected to tensile testing

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Abstract

There is evident effort shown by the global scientific community towards experimental investigation and characterization of cellulosic fibers geared towards optimizing cellulosic fibers for composite processing. Areas of attention include fiber chemical pre-treatment, composite architectural considerations such as the fiber loading effects and matrix hydrophilicity, amongst the others. On one hand, there has not been much exploration geared towards assessment and ascertainment of the effects and influence of test systems and environmental conditions particularly to mechanical testing with regard to conveying the quality of results. This research seeks to outline specific factors with adverse contribution to the results for cellulosic-fiber composites based on tensile test. By virtue of the tensile test's inherent similarity in configuration to stress relaxation and creep test, the methodology of quantification of doubt which exists about this test could also be applied to the latter two based on that the two tests are a paramount criteria for cellulosic fiber composites' long term performance characterization. Factors contributing to uncertainty of measurement have been identified and their respective effect quantified. This is in a bid to convey the quality of results and outline laboratory environmental elements to critically control and monitor in order to achieve authentic results. Relative humidity and temperature were observed to be the main contributors to uncertainty of measurement at 96.32% and 3.25 % correspondingly. The resulting expanded uncertainty exhibited levels in the margins of 20 %, which cautions for critical control of the environment and the testing system if consistently accurate results are to be assured.
Keywords: Uncertainty of measurement, tensile, cellulosic fiber composite, mercerization, sisal fiber

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1. Introduction

Every measurement or test has an error of measurement. If repeated, a test or measurement often gives a different result even though it is usually very similar to the original result (NMISA, 2009; Bell, 2000). This implies that a test gives only an approximation of the true value of the quantity to be measured. A measurement or test is therefore, only complete if it includes the measurement uncertainty of the test. Uncertainty of measurement can be thought of as a quantitative indication of the quality of the result (NMISA: 2009). Consideration given to the inherent complexity of the cellulosic fiber composite and the fiber's anisotropic nature, it becomes a worthy cause to quantify and evaluate the quality of the result for materials of such architecture. This owes particularly to their complex architectural variables based on its assembly, fiber-loading, matrix hydrophobicity and composite processing. The comparative advantage of the employed methodology of uncertainty of measurement is that it conveys the quality of results, identifies experimental constitutive parameters with adverse influence to test results, and quantifies the degree of their contribution to the overall effect. The methodology constitutes variables as proper mathematical models for uncertain quantities and co-opts simple probability distributions to represent forms of measurement uncertainties. For this application and bearing the need to establish the degree of accuracy of the test system, the methodology is advantageous when compared with others which employ mathematical intervals rather than a probability distribution. Examples of the preceding may include data manipulations involving periodic measurements, detection limits, or plus-minus ranges of measurements, where no particular probability

distribution seems justified, or where one cannot assume that the errors among individual measurements are completely independent.

Several research articles on cellulosic fiber chemical modification were reviewed with respect to factors affecting effectiveness of treatment. Yan *et al*., 2000 carried out a detailed and comprehensive review of sisal fiber properties, interfaces between thermoplastics and sisal fiber. They observed that sisal fiber exhibits effective reinforcement potential in polymeric matrices. With regard to authenticity of results, they cited experimental conditions namely fiber-diameter, gauge length, strain rate and test temperature as variables pertinent to the determination of any usable information on mechanical and physical properties of the fiber. It becomes the intent of this study therefore, to establish and estimate the effects of the test system and the laboratory environmental conditions on cellulosic fiber composites results. The goal of outlining and assessing the degree of contribution to uncertainty of measurement is to institute effective controls and monitoring of test systems and the environment under which testing is performed in order to achieve consistently accurate results. In the estimation of uncertainty of measurement, this study employs sisal fiber and isotactic polypropylene matrix in preparation of the composite for evaluation. Uncertainty of measurement was evaluated based on tensile test results for a composite material prepared from sisal fiber having undergone chemical modification with 25% NaOH solution concentration. The aforementioned alkali solution concentration level is obtained from part of the comprehensive research dedicated to optimization of sisal fiber strength by the same authors. Uniaxial tension tests on specimen of uniform gauge lengths were performed. Complementary to tensile testing from which uncertainty of measurement was approximated, impact testing, TGA and fracture surface morphology were studied to accord further insight on composite performance and effectiveness of fiber modification.

The methodology for evaluation of uncertainty of measurement involved identification of sources of errors and their types, determination of standard uncertainties, conversion of standard uncertainties to a similar scale and units through sensitivity coefficients and determination of the expanded uncertainty. Consultation was made to documentation prepared by a joint working group supported by Bureau des Poids et Mesures (BIPM), International Electrotechnical Commission (IEC), International Organization for Standardization (ISO), International Organization of Legal Metrology (OIML), and the National Physical Laboratory–UK (Cook, 2002, Kandil, 2000, Gabauer, 2000, Bell, 2001). The documents guides on how uncertainty statements are attained and also, provide a basis for international comparison of measurement results. The materials were extensively consulted and the generic principles applied to reach at reasonable scientific findings given this specific research discipline and scope.

2. Experimentation

2.1 Materials and sample preparation

2.1.1. Fiber origin and reagents: The sisal fibers used in this work were harvested locally. No information on fiber physical and chemical characteristics were available. Laboratory reagents used were sodium hydroxide pellets of 99% strength supplied by Rochelle Chemicals, South Africa. Chemicals were diluted to solution concentration stipulated in the pre-treatment protocol entailed in this article.

2.1 2. Fiber extraction: The fiber extraction procedure involved careful mechanical separation of the fiber from the inner core of the sisal leaves. Sisal fibers were stored for senescence at room temperature controlled at 23 ±1^{o}C and relative humidity of 57 ±3%. Fiber samples used were "ribbon fibers" extracted from the median line and mid-span region of the leaf.

2.2 Fiber treatment, analysis and testing of composite

2.2.1 Fiber Chemical-treatment protocol: A single batch of fibers were mercerized. The fibers were soaked in sodium hydroxide (NaOH) of 25% concentration, and then thoroughly washed with distilled water in a controlled bath at 21±2 ^{o}C for 48 hours. Fibers were then dried at room temperature for 48 hours. Fibers were subsequently soaked in 1% acetic acid to neutralize excess sodium hydroxide. Lastly, the fibers were thoroughly rinsed with distilled water, and then dried in an oven at 80 ^{o}C for 2 hours to remove free water.

2.2.2 Fiber analysis

2.2.2.1. Thermogravimetric Analysis (TGA): TGA was performed using the Thermogravimetric Analyzer – Pyris 1 supplied by PerkinElmer. Three samples each from the untreated and treated fibers were taken for TGA analysis. Sample amounts of about 6.866 *mg* of untreated and NaOH-treated fibers were analysed. All samples were analysed between 30 ^{o}C to 600 ^{o}C at 10 ^{o}C/min in Nitrogen atmosphere flowing at 20 ml/min.

2.2.3 Composite processing and testing

2.2.3.1 Preparation of the composite: Composite panels were prepared from isotactic polypropylene and mercerized sisal fibers at 0.3 fiber volume fraction of loading. In order to preserve the integrity of the fibers, the composite was processed at a temperature of 180 ^{o}C. The initial degradation temperature for the mercerized sisal fiber was about 230^{o}C as determined from TGA thermograms in Figure 3. Tensile test specimen were cut off from the prepared composite panels. Fifteen specimens were prepared for tensile testing according ISO 527-1. Samples were kept for 7 days within the laboratory to acclimatize to the environment. During testing, the first three samples were used for trial testing to "stabilize" the test system. Values for the subsequent twelve samples were reported on. Testing on all samples was performed in one day.

2.2.3.2. Impact Testing: Charpy impact testing was performed on the Zwick/Roell HIT 5.5 Pendulum impact tester using the 2.7J hammer. Testing was performed following ISO 179-1:2000. Figure 1 (a) shows the notched samples for Charpy impact testing. Figure 1 (b) illustrates the configuration for the edgewise impact blow. A total of five samples were tested for impact. Prior to test, samples were stored under a controlled laboratory condition of temperature 23±1 ^{o}C and 57±3% relative humidity for 48 hours to acclimatize.

(a) (b)

Figure 1 (a) alkali-treated v-notched samples, and (b) edgewise impact blow configuration.

2.2.3.3. Tensile testing: Tensile testing of the composite samples was conducted on the Zwick/Roell Z020 universal testing machine of 20kN maximum load cell capacity. Testing was performed following the ISO 527-1 standard. The specimen was cut to a dog bone shape and a gauge length of 50mm maintained. Test speed was maintained at 0.05 mm/sec. The tensile machine was interfaced to a computer where the configured parameters such as the load-extension graph were displayed. Testing proceeded in a controlled temperature and relative humidity of 23±1 ^{o}C and 57±3 % RH correspondingly. Figure 2 shows the tensile specimen positioned within the jaws of the tensile tester.

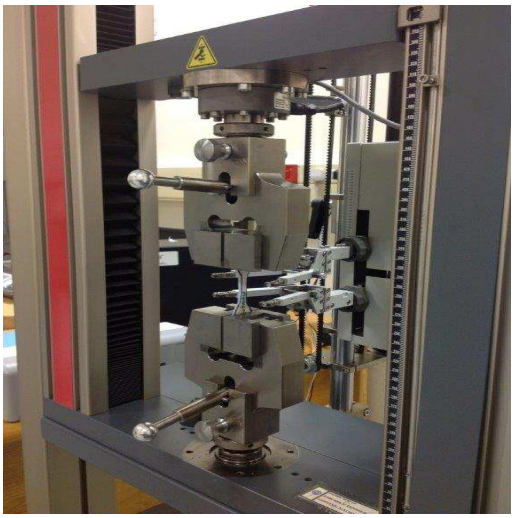


Figure 2. Zwick/Roell Z020 Universal testing machine illustrating sample positioning.

3. Results and Discussions

3.1 Thermal Gravimetric Analysis: Figure 3 shows the thermograms for the untreated and the treated sisal fibers. Parameters determined from the thermograms are shown in Table 1.

Table 1. Thermal degradation parameters for untreated and alkali-treated fibers

Degradation parameter (^oC)	Untreated fiber	Treated fiber
Initial degradation	174	230
Inflection point	335	379

The results indicate improvement of initial degradation from 174 to 200 ^oC for mercerized fibers when compared to the untreated fiber. This effect highlights that treated fibers can be processed at temperatures lower 200 ^oC safely whilst still maintaining their structural integrity. A similar shift in effect is observed for the inflection point (where the degradation rate is maximum leading to degradation of cellulose) and the final degradation temperature. The inflection points determined from the thermograms were 335 ^oC and 379 ^oC for untreated and mercerized fibers respectively. The results are consistent with findings by KifaniSahban *et al*., 1996 who observed that cellulose generally degrades at about 370 ^oC. Similar improvements in thermal properties have also been observed by Lu *et al*., 2012. They investigated thermal stability and thermo-mechanical properties of hemp-high density polyethylene composites. The authors reported improved initial degradation of hemp fiber from 225 to 251 ^oC following NaOH treatment.

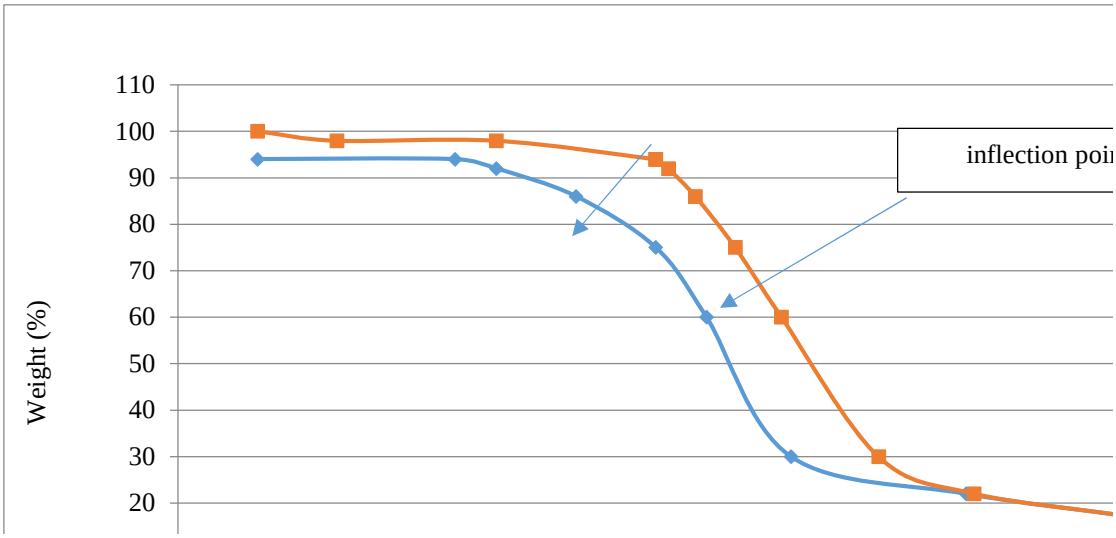


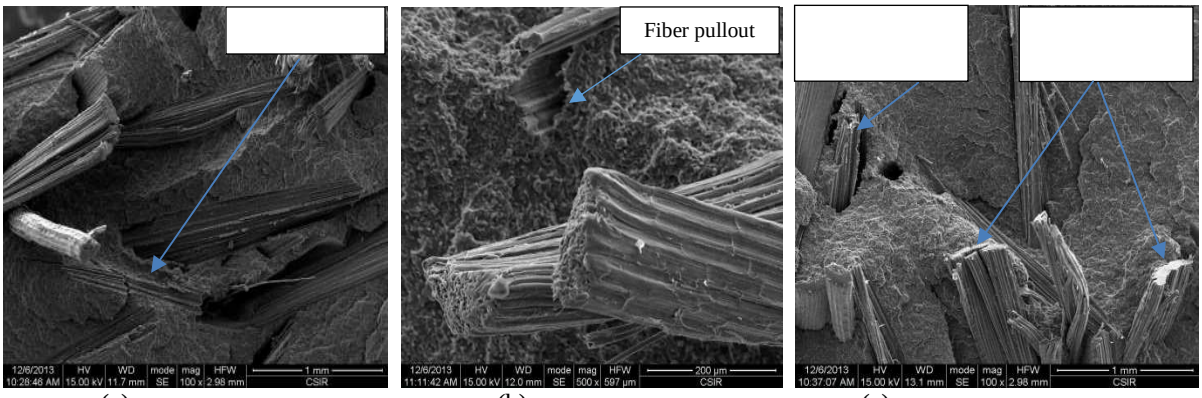
Figure 3. Reproduced TGA thermograms for untreated and alkali treated sisal fiber samples

3.2 Impact testing results: The v-notched Charpy impact strength of the treated sisal fiber reinforced composite results were studied to establish the fiber-matrix adhesion characteristics. Table 2 shows comparative results of the impact strength for the untreated fiber composite and the 25% NaOH treated fiber reinforced composite. Five composite specimens of each category were tested. The impact strength for the composite made from the 25% NaOH treated fiber decreased slightly compared to the composite made from the untreated fiber. Standard deviations of 0.66 and 0.29 were obtained for untreated and 25%NaOH treated fiber composites correspondingly. The higher standard deviation observed for untreated fiber may suggest a more pronounced variation of the natural state of the fiber, whilst the lesser standard deviation for the treated fiber may be attributed to improved structural packing order of crystallites conferring closeness of properties. The negative impact of the treated composite is attributed to improved fiber-matrix adhesion upon surface treatment, which led to fiber fracture rather than fiber pullout when subjected to mechanical shock. This observation if consistent with work by Li *et al*, 2011, who studied the effects of chemical treatment on properties of sisal fiber reinforced polylactide composites. They observed slight decrement in impact strength of surface treated composites compared to untreated fiber composites.

Table 2. Charpy v-notched impact results for untreated and alkali treated sisal fiber-polypropylene composites

Work of Fracture (kJ/m^2)		
	Composite from untreated fiber	Composite from 25% NaOH treated fiber
	8.79	7.48
	10.16	7.07
	8.58	6.96
	8.86	6.98
	8.61	7.0
Average	9.0	7.09
Std. Dev.	0.66	0.29

3.2.1 Fracture surface morphology: Figures 4(a) – (c) show the fracture morphologies of the composites from Charpy impact test surfaces. The figures depict fiber ends exposed from the surface of the matrix as a result of an impact fracturing the composite. Several different failure modes can be observed namely delamination, fiber pullout and fiber fracture. These failure mechanisms are consistent with findings by other researchers (Dao *et al*., 2012) who carried out investigation on formulation of energy release rate in the fracture mechanics of short fiber composites. Delamination, which is evidence of shear failure can also be observed mostly at Figure 4(a) implying weak bonding for composite processed from untreated fibers. Figure 4(a) and (b) from untreated-fiber composite exhibits almost intact fiber-ends indicating minimal energy dissipation at fiber ends possibly from poor mechanical interlocking. For treated fiber composites, remnants of treated fiber could be observed around the edges of resin sockets in Figure 4c. This effect is indicative of improved adhesion from the enhanced fiber-matrix affinity. In Figure 4(c), several sharply cut and smooth profiled fiber ends can be observed. The sharp-cut profile could probably be associated with the improved stiffness of the fiber as conferred by treatment, resulting in rapid fiber snapping on impact. Improved stiffness of the cellulosic fiber is a viable property for composite application. Similar failure characteristics have been observed by other authors (Carvalho *et al*, 2010) who studied on the chemical modification effects on mechanical properties of high impact polystyrene.



(a) (b) (c)

Figure 4. SEM micrographs of fracture surfaces for untreated samples (a) and (b), and alkali treated fiber (c)

3.3 Tensile Results: Figure 5 shows some of the tensile test curves for the composite prepared from the 25% NaOH treated fibers. The curve profile shows expected features of a cellulosic fiber composite where mechanical response is characterised by an initial linear response followed by a nonlinear transition to yield point. The behaviour of the processed composite is consistent with research work on cellulosic fiber composites by other researchers Carvallo *et al* 2011, Ghasemi *et al*, 2010 and Carvallo *et al*, 2010. The figure depicts the specific tensile curves for the 10.5MPa and the 12.8 MPa fibers, where each curve represents the sample tested. The obtained values of composite strength showed an average of 11.66 MPa and a standard deviation of 0.83.

3.2 Uncertainty of measurement: Together with the test system and the laboratory environmental condition, the results for tensile testing formed the basis for estimation of uncertainty of measurement. Estimation of uncertainty of measurement led to an expanded uncertainty fully expressed in section 4.3 of this article. For completeness of expression, the coverage factor and level of confidence chosen is also expressed alongside the expanded uncertainty.

4. Estimating uncertainty of measurement

The detailed estimation of uncertainty of measurement which follows is based on the laboratory testing environment, test system, and the results obtained from tensile test. The aforementioned elements are constitutive to the uncertainty of measurement evaluation framework. The representation of the final measurand namely tensile strength in N/mm^2, is determined from the force in Newtons and the sample cross-sectional area in mm^2

4.1Identifying sources of uncertainty for tensile testing of the composite: The sources of error considered to contribute to uncertainty of measurement together with their units and types are identified and listed in Table 3.

4.2 Calculating standard uncertainties and sensitivity coefficients: Table 4 shows the list of mathematical relationship used to calculate the standard uncertainties and the sensitivity coefficients together with their corresponding calculated results. For calculation of standard uncertainties, the parameters P = 95 %; n= 5; t=2.78 were used, where P is the confidence level, n is the number of measurements, f is the degrees of freedom and t is the student distribution factor. Various levels of confidence and student t values can be applied in the estimation of measurement uncertainty dependent upon the desired accuracy of presentation (JCGM, 2002; Bell, 2000; Cook, 2002).

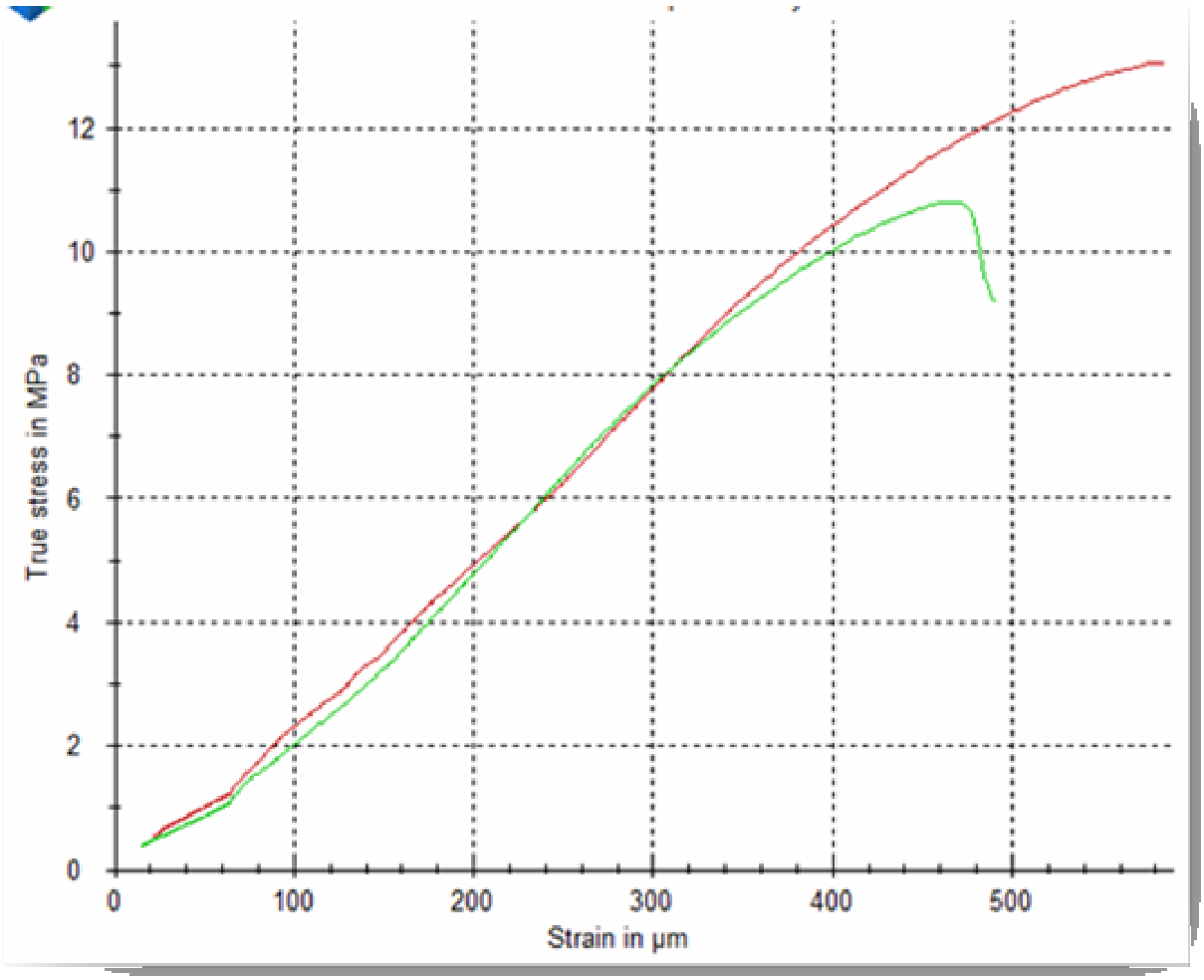


Figure 5. Tensile test curves for the two samples of the 25% NaOH treated fiber composites

Table 3. Parameters for which uncertainty was estimated (uncertainty budget)

Measurand	Units	Symbol	Type
Original cross-sectional area	mm^2	S_o	A
Stress	N/mm^2	σ	A
Strain	Mm	ε	A
Temperature	^oC	T	A
Relative humidity	%	RH	A
Load cell calibration	N	F	B
Speed of test	mm/sec	*v*	B

Evaluation of the sensitivity coefficient was done through partial differentiation of the equation that models the measurement, such that $c_i = \frac{\partial f}{\partial x_i}$, and also, by numerical calculation which approximated the differentiation process. The sensitivity coefficient determines the measure of sensitivity of the constituting parameter to the measurand (NMISA, 2009). Evaluation of sensitivity coefficients was applied by partial differentiation for tensile stress $\sigma = \frac{F}{S_o}$ where F is force and S_o the area; specimen cross-

sectional area $C_{so} = \left(\frac{F}{\sigma}\right)$ where F and σ represent force and stress respectively, and strain $\varepsilon = \frac{\sigma}{E}$ where σ and E represent stress and Young's modulus respectively. For temperature, humidity and speed of test where the functional relationship to the measurand was not known, the sensitivity coefficient was determined by temperature and humidity data recorded during testing. The values for sensitivity coefficients for temperature and humidity are presented at sections 4.2.2.1 and 4.2.2.2 respectively.

Table 4. Standard uncertainties and sensitivity coefficients for identified uncertainty contributors.

No	Standard uncertainty	Applicable mathematical relationship	Results
1	cross sectional area	$U_{so} = \sqrt{(b_o)^2 u_{ao}{}^2 + (a_o)^2 u_{bo}{}^2}$	0.0425 mm^2.
2	stress	$u_\sigma = \sqrt{\left(\frac{1}{S_o}\right)^2 u_F{}^2 + \left[\frac{F}{(S_o)^2}\right]^2 u_{so}{}^2}$	0.0072 N/mm^2
3	strain	$u_\varepsilon = \sqrt{\left[\frac{1}{L_o}\right]^2 u_\varepsilon{}^2 + \left[\frac{e}{L_o{}^2}\right]^2 u_{Lo}{}^2}$	0.000565 mm
4	temperature	$u(x_i) = \frac{a}{\sqrt{6}}$	0.408 ^{o}C
5	relative humidity	$u_H = \frac{a}{\sqrt{6}}$	1.2247 % RH
6	force (load cell)	$u_F = \left(\frac{u_E}{k}\right)^2$	0.16 N
7	speed of test	$u_v = \left(\frac{u_E}{k}\right)^2$	0.011025 mm/sec
Mathematical relationships for sensitivity coefficients			
1	cross sectional area	$c_{so} \Rightarrow C_{so} = \frac{\partial \sigma}{\partial S_o} = \frac{\partial}{\partial S_o}\left(\frac{F}{S_o}\right)$	-1.8780706
2	stress	$c_\sigma \Rightarrow C_\sigma = \frac{\partial E}{\partial \sigma} = \frac{\partial}{\partial \sigma}\left(\frac{\sigma}{\varepsilon}\right)$	1.141592
3	strain	$c_\varepsilon \Rightarrow C_\varepsilon = \frac{\partial E}{\partial \varepsilon} = \frac{\partial}{\partial \varepsilon}\left(\frac{\sigma}{\varepsilon}\right)$	-41.89797
4	temperature	$y = -0.1306\,x + 14.745$	-0.1306
5	relative humidity	$y = 1.2842\,x - 62.438$	1.2842
6	force (load cell)	$c_f \Rightarrow C_F = \frac{\partial \sigma}{\partial F} = \frac{\partial}{\partial F}\left(\frac{F}{S_o}\right)$	0.05869
7	speed of test	$C_v = \frac{\partial t}{\partial v} = \frac{\partial}{\partial v}\left(\frac{D}{v}\right)$	-0.10062289

4.2.1 Standard uncertainty in temperature, u_T and relative humidity, u_H : In the absence of a mathematical relationship for direct temperature effect existing for the experimental setup for this Type B uncertainty analysis, a triangular distribution was chosen for estimation. A divisor of $\sqrt{6}$ was used in calculating the standard uncertainty $u(x_i)$ for temperature. The triangular distribution was chosen on the basis that the recorded room temperature values concentrated the centre of the interval (23^{o}C) were considered more credible than values dispersed near the boundaries. For relative humidity, a triangular distribution was also chosen based on a similar premise as for temperature.

4.2.2 Calculation of sensitivity coefficients: The presented seven uncertainty contributors whose standard uncertainties have been determined are presented in different units. For dimensional correctness in their aggregation, the uncertainty contributors have to be converted into the same units as the measurand (Gabaeur, 2000; Kandil, 2000; JCGM, 2008) namely tensile strength in MPa. Conversion of uncertainty contributors into the same units as the measurand was achieved through application of the sensitivity coefficient.

4.2.2.1 Sensitivity coefficient for temperature, c_t : The Figure 6 depicts the recorded levels of tensile strength of the composite against temperature prevailing within the laboratory during testing. Five temperature readings recorded for the duration of testing were 23.36 ^{o}C, 23.36, 23.41, 23.41 to 23.41^{o}C. The sensitivity coefficient c_t was obtained as the gradient of the plot for tensile strength against temperature.

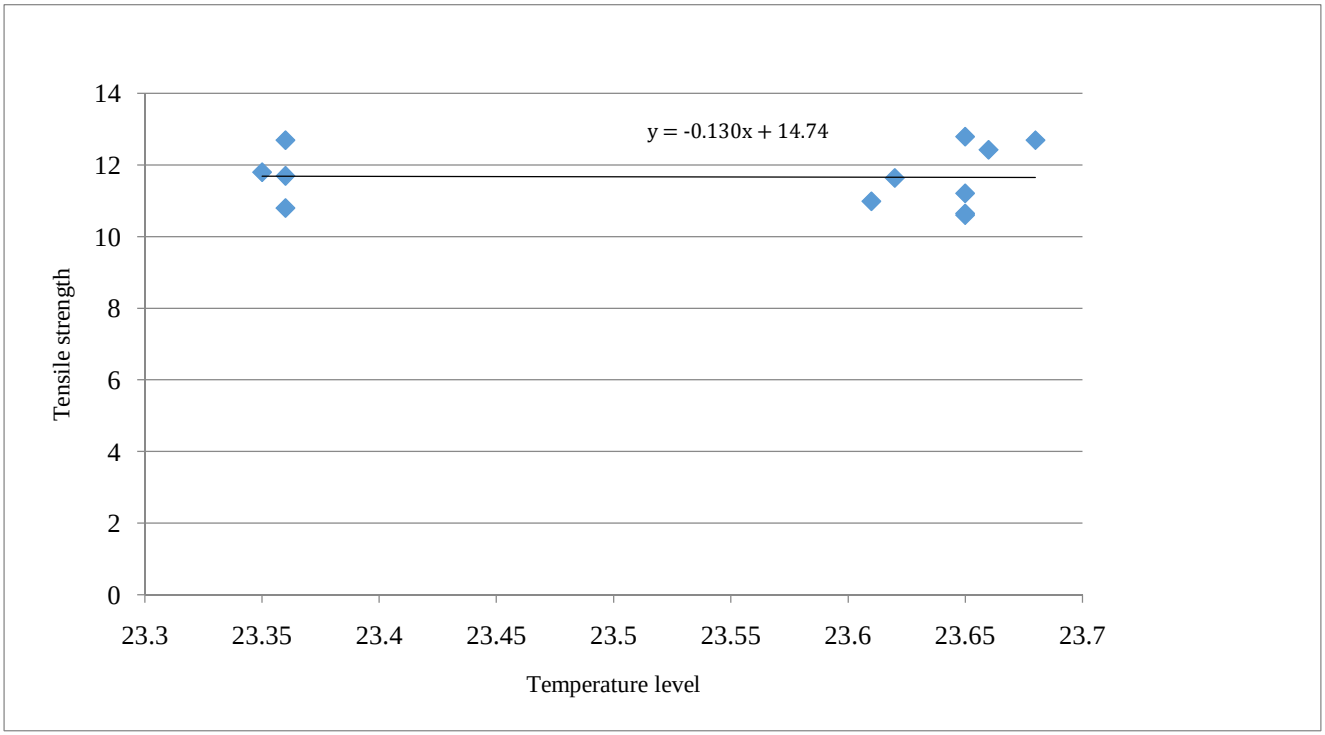


Figure 6. Variation in Tensile strength as a function of Temperature

4.2.2.2 Sensitivity coefficient for humidity, c_h : The Figure 7 illustrates the levels of tensile strength of the composite against humidity prevailing within the laboratory for the duration of test. Five humidity readings recorded for the duration of test were 57.64, 57.60, 57.27, 57.74 and 57.74 % RH. The sensitivity coefficient c_h was obtained as the gradient of the plot for tensile strength against humidity.

4.3Combined uncertainty and expanded uncertainty: Following calculation of standard uncertainties for individual uncertainty contributors and their associated sensitivity coefficients, the contributors were combined to produce the combined uncertainty. The expanded uncertainty was obtained by multiplying the coverage factor and the combined standard uncertainty (NMISA, 2009). Table 5 shows the resultant mathematical relationships for the combined uncertainty and the expanded uncertainty together with the corresponding yielded results.

As final expression, the expanded uncertainty is 12.80 ± 2.55 MPa, based on the standard uncertainty multiplied by the coverage factor k = 2, at a level of confidence of approximately 95%.

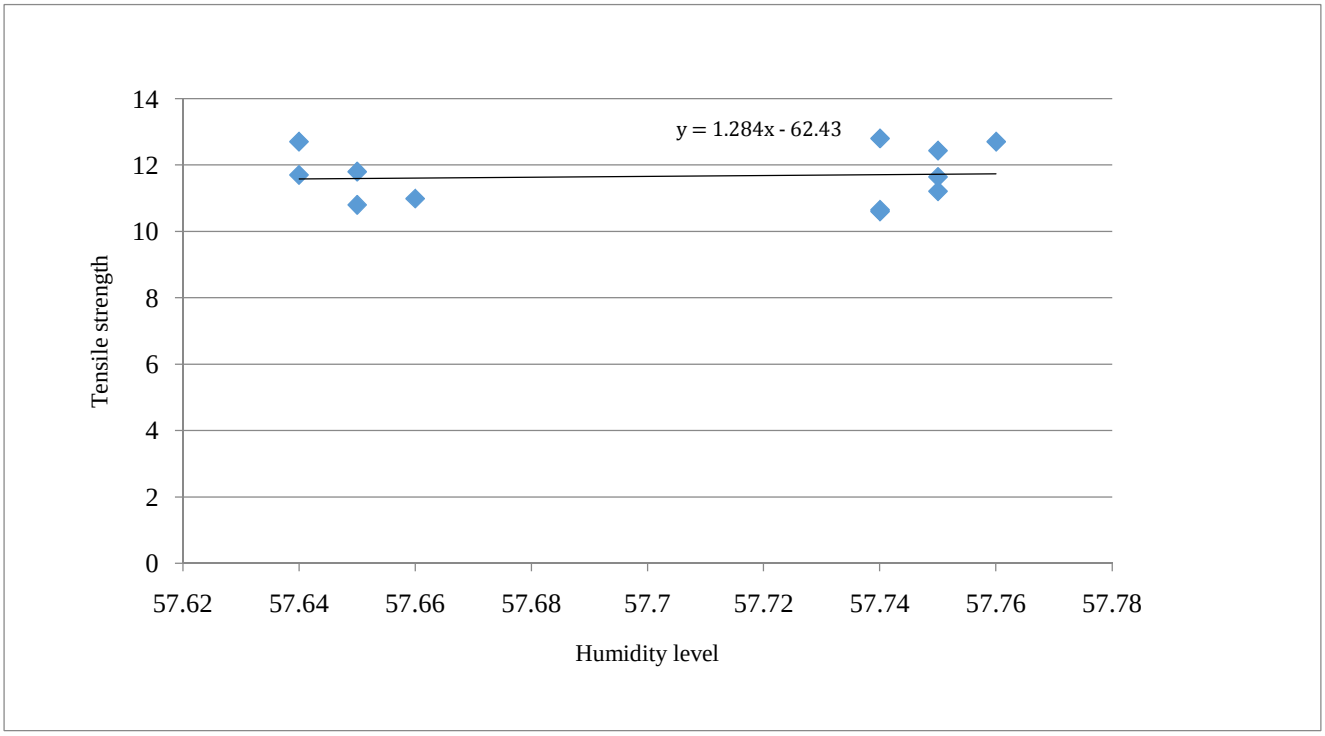


Figure 7. Variation in Tensile strength as a function of Humidity

Table 5. Combined uncertainty and expanded uncertainty results

Parameter	Applicable mathematical relationship	Results
Combined uncertainty $u_c(y)$	$\sqrt{(c_{So}u_{So})^2+(c_\sigma u_\sigma)^2+(c_\varepsilon u_\varepsilon)^2+(c_T u_T)^2+(c_H u_H)^2+(c_F u_F)^2+(c_v u_v)^2}$	0.6978757
Expanded uncertainty U	$kxu_c(y)$	2.5556

5. Conclusions

This study has established and estimated effects of the test system and the laboratory environmental conditions on cellulosic fiber composites experimental results. This was performed with the intention to highlight and assess the degree of elements contributing to uncertainty of measurement. Consequently, the measure informs institution of effective controls and monitoring of the test system and the environment for achievement of consistently accurate results. Based on the findings from this study, the following conclusions are drawn:

- Temperature and humidity are critical elements within the test environment requiring close attention and control during evaluation of mechanical properties for cellulosic-fiber composites.
- The main contributors to uncertainty of measurement were humidity and temperature, at a contribution of 96.32% and 3.25 % correspondingly.
- The expanded uncertainty of 12.80 ± 2.55 MPa exhibits margins of 20 % strength variation. This level of margin may be considered significant. The margin cautions for critical control and monitoring of elements constitutive of the framework for estimation for uncertainty of measurement in the evaluation of cellulosic fiber composites.

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Biographical notes

R. Batane holds a B. Eng in Mechanical Engineering from TUNS, Canada. He also holds an MSc in Mechanical Engineering (Manufacturing and Materials) and a PhD in Mechanical Engineering (Materials Science) from Clarkson University, USA. He has been engaged with lecture work at the University of Botswana since 1998 in the discipline of materials science, prior to which he was with industry as a consultant in design and project management for mechanical engineering projects of national interest. R Batane participates in a number of technical committees related to national standardization work primarily in the areas of metal casting. He is also engaged with the National Training Authority at curriculum development for technical colleges. Dr Batane is one of the team members representing the country in the global natural fibre forum. He has supervised students at MSc level and carried out research in the broad area of material science. His main interests are in cyclic plasticity and fatigue behaviour of ultra-fine grain materials and also cellulosic fiber composites. He has published many articles in international journals and presented at international conferences on preceding enunciated disciplines. His current area of interest is in cellulosic-fiber properties optimization and characterization, with extension to modeling of composite performance via finite element methods.

N. Mokaloba holds a B. Eng in Mechanical Engineering from University of Botswana (1998). He also holds an Honours Degree in Metallurgy (2004) and an MSc in Chemical Engineering (2006) from University of Pretoria. His main areas of study were physical and mechanical metallurgy, heat treatment of steels, phase transformation in metals & their alloys and metallurgy analysis problems. In chemical engineering his emphasis was in polymer science, polymer processing, and polymer engineering. He is presently a test engineer (engineering materials) with Botswana Bureau of Standards, where he has been responsible for quality evaluation of engineering materials and products for the past 14 years, especially polymers. He is at an advanced stage of conclusion of his PhD research related to optimization of properties of natural-fibers and characterization of composite time and rate dependency, with the Faculty of Engineering & Technology, University of Botswana. He has published articles in the broad area of optimization of cellulosic fibers and their applications. He has presented at conferences in the preceding enunciated areas of research.

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