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EFFECTIVENESS OF PRE-SCREENING TEST FOR SAFE DESIGN OF COMPONENTS FABRICATED WITH ABACA NATURAL FIBERS A. Dabet Department of Mechanical Engineering, Faculty of Engineering Universitas Malikussaleh, Lhokseumawe, Indonesia H.

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ABSTRACT Natural fibers are considered as the most ecological material, but their mechanical properties widely vary from one fiber to another.

To use natural fibers for component of a structural material, the wide scatter in tensile strength must be reduced to a certain level. This research aims to develop a method that can reduce the wide scatter in tensile strength of natural fibers. Pre-screening test was proposed here for one of the methods and the effectiveness was examined using experimental results on tensile strength of virgin and surviving fibers after the pre-screening test.

It was indicated that three-parameter lognormal distribution could well characterize the experimental results, and the threshold tensile strength in three-parameter lognormal

distribution could be related to allowable stress for strength design. Key words: abaca fiber; pre-screening test; three-parameter, lognormal distribution. Cite this Article: A. Dabet, H. Homma, H. Homma, F. E.

Gunawan, Effectiveness of Pre-Screening Test for Safe Design of Components Fabricated with Abaca Natural Fibers, International Journal of Mechanical Engineering and Technology 9(13), 2018, pp. 1207 – 1215. http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=13 A. Dabet, H. Homma, H. Homma, F. E. Gunawan http://www.iaeme.com/IJMET/index.asp 1208 editor@iaeme.com 1.

INTRODUCTION Extensive researches on development of ecological or environmentally friendly materials are carried out to mitigate global warming. Steel makers in the world are developing advanced high strength steel for automotive industry to reduce plate thickness of vehicle structures, eventually aiming to lighten vehicle weight and resulting in enhancement of fuel economy [1].

On the other hand, composite material manufacturers are developing fast fabrication techniques of composite materials for mass production of car parts [2]. Life Cycle Assessment (LCA) of total $CO_2$ emission is evaluated to judge whether a material is really environmentally friendly in a whole usage period from raw material mining to depositing after usage. $CO_2$ emission of metallic and plastic materials is rather high, for instance, it is around 2.0 t $CO_2$ emission/t steel [3] and 4.6

to 8.7 t CO2/t epoxy resin [4]. In addition, that of carbon fiber used for carbon fiber reinforced plastics (CFRP) is around 24 to 31 t CO2/t carbon fiber [5]. Density of CFRP is much smaller than metallic materials. Consequently, vehicles and aircrafts fabricated with CFRP are significantly lighter and lower emission of CO2 than metallic vehicles and aircrafts in their life cycle [6].

Therefore, composite materials reinforced by strong and advanced fibers such as carbon, glass, and kevlar fibers, are considered as environmentally friendly materials. However, as described above, LCA of $CO_2$ emission of the advanced fibers is not necessarily low. Recently, many researchers pay attention on cellulosic natural fibers considering low carbon footprints.

Cellulosic natural fibers are extracted from leaves, trunks, basts, and seeds of plants. Absorption of $CO_2$ by photosynthetic reaction during growing process can be considered negative carbon footprints contrary to positive one by $CO_2$ emission during depositing process of burning and chemical decomposition.

Thus, LCA of $CO_2$ emission for cellulosic natural fibers is much lower than one of synthetic fibers like carbon fibers, glass fibers, and kevlar fibers. For instance, LCA of $CO_2$ emission for flax fibers is 1.07 t $CO_2$/t flax fiber [6], which is around 5 % of one for carbon fiber. There are several cellulosic natural fibers that have been used for clothes, bank bills, papers, marine cordages, handicrafts such as a bag, a floor mat, a tray, and others. Recently, application of natural cellulosic fibers to engineering structural components was initiated merely in automotive industry.

Layth Mohammed et al [7] summarized what kinds of natural fibers were used by automotive companies. When natural cellulosic fibers are used for engineering structural components, one of critical issues is wide scattering in fiber strength. An index of scattering in tensile strength is a ratio of standard deviation to mean value, which is called coefficient of variation.

The coefficient of variation of natural fiber strength is larger than 0.28 for jute, coir, piassava, and sisal [8], while for man-made materials like steel, E glass and aramid, the coefficient of variation is less than 0.14. In the previous work [8], the authors showed that statistical properties of abaca fiber tensile strength can be well expressed by lognormal distribution rather than Weibull distribution.

In addition, the authors showed that tensile strength of abaca fiber was widely scatted from 100 MPa to 850 MPa in the experiment and proposed an idea concept of a pre-screening test to reduce the scatter band. In this work, pre-screening test practice is presented and its effectiveness is discussed by statistical approach. 2. PRE-SCREENING TEST Effectiveness of Pre-screening Test for Safe Design of Components Fabricated with Abaca Natural Fibers http://www.iaeme.com/IJMET/index.asp 1209 editor@iaeme.com 2.1. Specimen Preparation In the previous experiment [8], seventy abaca single fiber samples were used for statistical approach.

Diameters of the samples varied from 0.06 mm to 0.14 mm and the frequency was almost uniformly distributed in a seven-bin histogram.

Diameters of the samples varied from 0.06 mm to 0.14 mm and the frequency was almost uniformly distributed in a seven-bin histogram. Preparation of specimens for pre-screening test was made in accordance with the following steps: ? Diameters of abaca fiber samples were measured and divided into seven groups (bins) of which diameter variation width was the same as the bin width of the histogram [8] until the sample number in each bin reaches 45.

? Forty-five fibers in each bin were bundled to prepare a pre-screening specimen. Bin 5 to 7 pre-screening specimens were consisted of two specimens that contained 22 and 23 fibers to make the bundle diameter of less than 4.0 mm. ? Each end of the fiber bundle was looped around a short metal tube and surplus of the end part was laid on main part of the fiber bundle to be glued.

Figure 1 Specimen configuration and dimensions The specimen configuration and dimensions are shown in Figure 1. The specimen gage length was around 100 mm and specimen cross section area was calculated as total area of all fiber cross section as shown in Table 1. Table 1 Cross section area of pre-screening test specimen 2.2.

Loading Method Pre-screening test aims to select fibers of which tensile strength is stronger than a critical value. In the pre-screening test, a bundle of fibers was used as a test specimen. In this work, the tensile strength not specified be modulof the abaca fiber was not known. A pre-screening specimen contains fibers of various strengths and some fibers may break at rather low stress.

If such premature fracture of fibers takes place under a load-controlled loading system, the surviving fibers must bear the load that was born by the prematurely fractured fibers to result in fracture of all fibers. Therefore, in this work, Bin No. Diameter variation width mm Total cross section area mm2 1 0.006-0.025 0.149 2 0.025-0.044 0.216 3 0.044-0.063 0.286 4 0.063-0.083 0.360 5 0.083-0.102 0.214(5-1), 0.224(5-2) 6 0.102-0.121 0.261(6-1), 0.267(6-2) 7 0.121-0.140 0.313(7-1), 0.331(7-2) the fiber bundles were subjected to a displacement-controlled loading.

An end of a pre-screening specimen was placed in a U-link clevis that was connected to a cantilever load cell mounted on the bottom of the loading frame. The other end of the specimen was placed in a U-ling clevis connected to micro-meter head fixed on the upper of the loading frame. The specimen end was displaced by turning the micro-meter head.

When the premature fracture of weak fibers takes place in the displacement-controlled loading frame, applied load drops and load born by surviving fibers is remained at the same level as one before the premature fracture. In the pre-screening test, each bin bundle specimen was loaded until the load steeply dropped. Unfortunately, it was quite difficult to specify how many fibers survived during experiment.

In this work, after unloading, surviving fibers were carefully inspected and total cross section area of surviving fibers was calculated to estimate the survival stress from the final load and the total cross section area of the surviving fibers. It is rather troublesome to measure fiber elongation during the pre-screening test. Two-dimensional numerical analysis using ANSYS ver.

13 was carried out to estimate elongation in gage region of a specimen. A half of the specimen shown in Figure 1 was broken down up to around 2500 eight-node-square meshes contapairs Ymodulof an abaca fiber is not definitely identified yet. Nevertheless, it is inevitable to the numerical anal. ereYoumodulwas to GPa 20 rerring e shed data 9]In ion, musttake o ccoufiber er epenoYouns modul[.

y wed Young's us jut fiber significantly depended on fiber er. g'smodulof e r ecrefrom GPato GPa diameter increased from 0.06 mm to 0.140 mm. Numerical analysis was conducted for two Young's i. the nal, mipoint of specimen was fixed in loading direction and top end of a steel ring was displaced by 4.0 mm. Load and displacement diagrams were almost linear. In Figure 2, displacement distribution along the specimen axis is shown for bin 7 specimen of which Young's modulus is 20 GPa.

Figure 2 Displacement along specimen center line calculated by FEM As shown in the figure, displacement linearly increases with distance from the specimen center and then, the slop decreases to a half in the loop region, because the cross section area becomes twice. Displacement suddenly jumps up at steel ring. This behaviour results from elongation of fiber bundle surrounding the steel ring.

It should be noted that the steel ring end and the fiber bundle are displaced by 4.0 mm while the other end of the ring is displaced by less than 4.0 mm and eventually, the steel ring was deformed in an elliptical shape. When a half of the specimen was elongated by 4.0 mm, the specimen gage region was strained by 4.8 %.

If it is hypothesized that a fiber bundle specimen is fabricated in a uniform cross section without the steel rings, equivalent half specimen length is 83.3 mm, so that the specimen was  subjected to 4.8 % strain by 4.0 mm elongation. The equivalent total specimen length was calculated r g's us 6.9

and GPa specimof 1 Bin It varied from 161.2 to 166.6 mm. When the specimen was elongated by 2.0 mm, the strain was calculated as 1.24 % and 1.20 % for the equivalent specimen length of 161.2 mm and 166.6 mm, respectively. It should be noted that the equivalent total specimen length can be substantially regarded to the average, 163.9 mm of 161.2 mm and 166.6 mm.

Namely, in the test, displacement of a U-link specimen grip was measured to calculate strain in the specimen gage region by use of this equivalent specimen length. 3.

EXPERIMENTAL RESULTS AND STATISTICAL ANALYSIS 3.1. Results of Pre-Screening Test Pre-screening test result is shown in Figure 3 for bin 7-2 specimen. The displacement is one of a micro-meter head connected at a U-link specimen grip end.

The grip was made of steel, and deformation of the grip could be neglectable because applied force was small. The diagram steadily rises with small steps called pop-in behaviours. The pop-in phenomenon may be caused by sudden fracture of a small bundle of fibers. After reaching the maximum, the load suddenly drops. This may result in break at the majority of fibers.

The pre-screening test was terminated at the sudden load drop. After pre-screening test, the loops of each bin bundle specimen were cut to measure the fiber length. If the fiber length was less than 100.0 mm, the fiber was identified as a broken one. Then, surviving fibers were collected for each bin bundle specimen. The number of surviving fibers and other experimental data are summarized in Table 2.

Survival ratio are around 20 to 30 % in each bin specimen while it is more than 40% for bin 7-2 specimen. Surviving fibers were less than a half of initial fibers. The 10 surviving fibers of each bin specimen are used for single fiber tensile test. Table 2 Data of pre-screening test for each bin fiber-bundle specimen Figure 3 Example of load-displacement diagram in pre-screening test A. Dabet, H. Homma, H.

Homma, F. E. Gunawan http://www.iaeme.com/IJMET/index.asp 1212 editor@iaeme.com The maximum displacement is indicated in the second row. It varies from 2.85 mm to 4.14. The maximum strain was calculated as the third row from the maximum displacement and effective gage length 163.9 estimated from the numerical analysis. It is roughly 0.02. The survival stress was calculated by the final and total cross section area of surviving fibers.

The calculated survival stress is corresponding to the critical stress in the pre-screening test. The minimum survival stress is 128.9 MPa and this is regarded as the critical stress of the pre- screening test in this work. 3.2. Statistical Analysis of Single Fiber Tensile Test To examine Effectiveness of Pre-screening Test on quality assurance, statistical analysis was carried out for virgin fibers and surviving fibers after the pre-screening test

Since it was mentioned in the in the previuos work [8] that tensile strength of abaca fiber was well characterized by lognormal distribution, lognormal distribution was utilized for the statistical analysis of tensile strength of surviving fibers after pre-screening test. Three-parameter lognormal distribution is considered more appropriate for the statistical analysis of Tensile strength surviving fibers.

Three Three parameters were estimated by use of combination of Quantile method and Probability Weighted Moment method [11]. Probability density function of three-parameter lognormal distribution is given as ( ) v ( ) { [ ( ) ] } (1) where , , and m were estimated standard deviation, mean value, and threshold value from experimental results. Those parameters are given as functions of three probability weighted moments.

When m is estimated by Quantile method, other two parameters are easily calculated. They were 0.389, 5.77, and 0, for virgin fibers, respectively. Quantile method estimated m as -64.7, but m should be larger than zero for lognormal distribution. Then, m was set as zero for the virgin fibers. In Figure 4, probability density calculated from a seven- bin histogram is compared with estimated log-normal probability density.

It can be seen that the estimated lognormal probability density function well fit with experimental results, because sum of squared residuals for seven experimental results is 1.317 E-6. On the other hand, single fiber tensile test was carried out for surviving fibers after pre-screening test. The same method was applied to experimental results to calculate the parameters of 3-parameter lognormal distribution. The threshold value m was calculated as 78.9

MPa by Quantile method and mean value and standard deviation were calculated as 5.500 and 0.813, respectively. Probability density curve calculated from estimated parameters did not well fit experimental results. Threshold value is calculated from sample data by several ways. In this work, 10-percentile data were used to calculate the threshold value. As mentioned above, the probability density curve did not fit experimental data.

Then, in this work, the minimum strength in the experimental result were used for the threshold value. The estimated threshold value, mean value, and standard deviation were 185.0 MPa, 4.967, and 0.694, respectively. In Figure 5, probability density is shown to compare with experimental results. A solid line is the probability density for the threshold value of 185.0 MPa.

It can see that the calculated 3-parameter log-normal probability density well agree with experimental data. In the figure, the probability density for virgin fiber is also shown with a broken red line for comparison. The probability density for the pre-screened fibers is likely to express truncated probability density of the virgin fiber, and has remarkably large peak value resulted from addition of the truncated part.

It should be noted that tensile strength of pre-screened fiber can be well characterized by 3- parameter log-normal distribution.

It is natural, because the pre-screening test aims to specify the threshold strength of pre-screened fibers as a certain value. 4. EXAMINATION OF EFFECTIVENESS OF PRE-SCREENING TEST From the pre-screening test, the survival stress was estimated as 125.8 MPa. On the other hand, the experimental probability density was well expressed by 3-parameter lognormal distribution with the threshold strength of 185.0

MPa that is the minimum tensile test of the surviving fibers. This means that the survival stress at the pre-screening test is conservative for the minimum strength of the pre-screened fibers. In Figure 6, cumulative fracture probability of the surviving fibers is shown.

A blue line is cumulative probability calculated from the 3-parameter lognormal probability density function estimated in the above. A red broken line is one from 3-parameter lognormal probability density with threshold value calculated by a pivotal quantile Figure 4 Comparison between experimental result and estimated lognormal distribution Figure 5 Probability density of tensile strength for pre-screened fibers A. Dabet, H. Homma, H. Homma, F. E.

Gunawan http://www.iaeme.com/IJMET/index.asp 1214 editor@iaeme.com method [12]. Tow lines almost coincide each other in the range of more than 300 MPa. As seen from the figure, cumulative fracture probability well agrees between experimental data and a red broken line. The red broken line shows that the stress of less than 140 MPa, the fracture probability is less than 10-6.

Therefore, for the surviving fiber after this pre-screening test, 140 MPa can be adopted as allowable stress for design. 5. CONCLUSIONS pre-screening test was proposed to specify threshold strength of natural fibers in order to use natural fiber for structural materials. Experimental result showed that the proposed pre- screening test could reasonably provide allowable stress to design a mechanical component safely using natural fibers.

The pre-screening test method is still under development, thus this work showed that since the concept of the pre-screening test was fairly effective, further research work will be continued to develop the effective pre-screening test method ingeniously.
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