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Ships in Composite Materials

ASTM Standard for burn-off tests and flexural tests – Task 1A

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1. Introduction

The goal of this project is to get expertise with experimental methodologies and basic theoretical methods for calculating the strength and stiffness of a typical maritime laminate. It is necessary to comprehend the assessment of experimental data and theoretical calculations considering some of the strengths and limits of both techniques. The American Society for Testing and Materials ('ASTM Standard') test "Standards" will be examined.

Before it is important for the applicability of a material to know its mechanical properties, particularly if it is a composite material with more than one material component and its chemical compositions and method of manufacturing can change the way the composite behaves when subjected to loads, it is important to understand how these mechanical properties can be estimated for different types of composites and/or compositions. The primary goal of this research is to explore and become acquainted with the processes for determining the strength and stiffness of a maritime laminate.

This review examines the content and basic information necessary to fulfil an Ignition Loss test of Cured Reinforced Resins and a Flexure test for Unreinforced and Reinforced Plastics and Electrical Insulating Materials in order to deduce their flexural properties, in this case specifically for a hand laid up laminate with polyester resin. It will be a manually laid-up glass fiber laminate with polyester resin, as previously mentioned. All of the methods detailed here are in accordance with ASTM standards (American Society for Testing and Materials).

This report will be broken into two sections, the first dealing with the burn-off test and the second with the flexural test.

2. Ignition Loss of Cured Reinforced Resins

For first step in this topic, the standard regulation for this sort of test was examined, which has the scope of observing and calculating how much volatile content the materials have, in this case for a specific reinforced resin. This sort of test involves delivering enough heat to a specimen in a controlled environment to cause it to burn until only ash and carbon remain, then measuring the mass of the specimen and calculating the ignition loss.

For instance, only if an organic resin reinforced with a glass fabric is used as the specimen and other elements of the composite such as residual solvent or water are ignored, the ignition loss can be credited to the resin because it completely converts into volatile materials when revealed to a certain amount of heat.
The following elements demonstrate the circumstances and equipment required for this sort of test to be performed in line with the standard rule.

Equipment Required:

- *A 30 mL platinum or porcelain crucible*
- *A 565+28°C Electric Muffle Furnace capable of achieving and sustaining that temperature.*
- *A desiccator large enough to hold the crucible.*
- *Bunsen Flame*
- *Balance.*

Figure 1- Porcelain Crucible

Figure 2 - Electric Muffle Furnace

Figure 3 – Desiccator

Figure 4 - Bunsen Flame

Figure 5 - Balance

Test specimen:

- A minimum of three specimens should be evaluated for each material sample;
- Maximum dimensions of 2.5 by 2.5 cm in thickness, with a mass of roughly 5 g.

Before being weighed and burned, specimens must have been tested for mechanical properties (flexural or tensile strength), and they must be dry and free of cracks, with smooth and untorned faces.

Conditioning:

- The specimens should kept at a temperature of 23 ± 2ºC and a relative humidity equal to 50 ± 5% for 40 hours or more before the test.

Procedure:

- First, the crucible should be heated for at least 10 minutes at a temperature between 500°C and 600°C ;
- Bring the crucible to room temperature in a desiccator and measure its mass;
- Place the specimen in the crucible and measure its mass;
- Heal the crucible and specimen in a Bunsen flame until the specimen ignites.
- Place the crucible and specimen in the muffle furnace at a temperature of 565+/- 28°C until all carbonaceous material has vanished. (Depending on the specimen shape, this process can take up to 6 hours to complete);
- Cool down to room temperature in the desiccator and weight.

After completing this method and recording all essential measurements, the ignition loss may be estimated using the following formula:

$$\text{Ignition loss, weight \%} = [(W_1 - W_2)/W_1] \times 100$$

Where:
- W1 = specimen weight (in grams).
- W2 = weight of residual residue (in grams).

When the test is required to be done on three specimens, the average value and standard deviation should be calculated:

$$s = \sqrt{[\Sigma X^2 - n(\bar{X})^2]/(n-1)}$$

Where:

- s = estimated standard deviation
- X = a single observation's value
- $\overline{X}$ = the collection of observations' arithmetic mean value

The ignition loss range should be computed by subtracting the lowest specimen ignition loss from the greatest specimen ignition loss.
The computed values, as well as the material identity and any irregularities, such as melting, should be recorded.

Precision & Bias

Because this sort of test is very dependent on the geometry of the specimen and the manner in which the test was developed, the only way to generalize the findings acquired from different laboratories that execute the experiment is to establish standards for the acceptance of the data. The applicable rules are related to the subjects 11.2.1 and 11.2.2, which discuss repeatability and reproducibility, respectively.

Conclusion

Based on the examination of the provided documentation, it is concluded that exact equipment is required for these types of tests in order to produce correct findings; the geometry of the specimens is also important for the results and should be treated as specified by the ASTM.

3. Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

It seeks to determine the flexural characteristics of various materials, to graphically portray the flexural stress-strain curve, and to estimate the flexural strength modulus and the amount of energy required to cause a specific deflection of the material. In general, this test involves applying load to a simply supported beam with two supports and a loading point in the center of the supports. It should be noted that the flexural strength can only be evaluated if the tested material fails or breaks in the outer surface before reaching 5% of the strain limit. The studies are grouped into two techniques that are similar in execution but have slightly distinct goals:

- Procedure A is intended for materials that break at very minor deformations and is used to Flexure characteristics, notably the flexural modulus, must be measured.

- Procedure B is designed for materials with high amounts of deflection and is used to test flexural stiffness strenght.

Methodology

As previously stated, this flexure test involves applying a timely load to a bar with a rectangular cross section that sits on two supports. The load is applied to the supports in the centre. Supports with a span-to-depth ratio of 16:1 or above are utilized as a criterion to guarantee that the recorded deflection is exclusively relative to the specimen (in certain laminated materials).

When the load is given at a rate of 0.01 mm/mm/min for Procedure A and 0.1 mm/mm/min for Procedure B, the specimen begins to deflect until it reaches the rupture point or reaches the maximum strain. If the material is not defective until the maximum strain, it may be more effective to do a 4-point bend test for this laminate which differs in terms of the location of the maximum bending moment and maximum axial fiber stress.

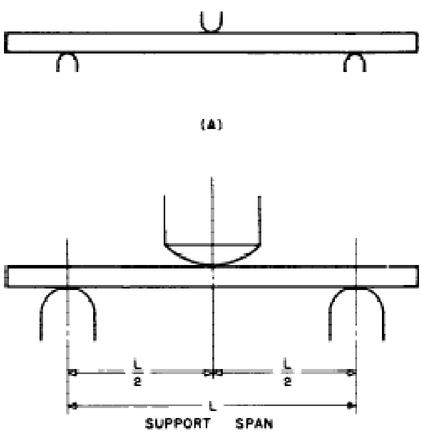

Fig.1 Example of test

Equipment

- Calibration of the testing machine is required in order to apply the load at a consistent rate of crosshead motion. A deflection measurement instrument should also be included in the machine. It is vital to remember that the load measurement system error must not exceed +/- 1% of the maximum load intended to be measured. Furthermore, the testing machine's stiffness must be such that the overall elastic deformation of the system does not exceed 1% of the total deflection of the test specimen throughout testing.

- Loading Noses and supports should be cylindrical in shape to avoid excessive indentation on the specimen and failure owing to stress concentration at the points of contact. The radius of the supports must be at least 5+/- 0.1 mm. If the specimens are deeper than 3.2 mm, the supports must have a minimum radius of 5+/- 0.1 mm, and the loading nose must have a minimum radius of 3.2 mm or bigger (minimum of 1.6 times the specimen depth). The loading nose's maximum radius must be no more than four times the specimen depth.

- Micrometers: Appropriate micrometers are required to measure the dimensions of the specimen (width and thickness).

Specimens for Testing

Because the behavior of the specimens in terms of deflection can vary greatly due to the thickness and position of the specimen during the test (flatwise or edgewise), it is important to note that for Sheet materials (Except Laminated Thermosetting Materials and Certain Materials Used for Electrical Insulation, Including Vulcanized Fiber and Glass Bonded Mica) thicker than 1.6 mm, which is the case of the presented specimen for this study (3 mm), it is recommended that should have 12.7 mm in width at least 10% of the support span overhanging on the end of each support.

Provided from the suggested specimen length for Molding Materials is 127 mm, a support span of 100 mm should be adequate to conduct the flexural test. It is also stated that in some cases, the surfaces of the specimens must be altered (machined) to provide the desired dimensions, which can result in significant changes in the obtained values; therefore, this information must be registered, and in the case of specimens that are machined only on one surface, it must be specified whether it was on the tension or compression side of the beam.

The specimens for laminated thermosetting materials and plate materials used for electrical insulation should be machined on both surfaces, as indicated in subject 7.3. The support span should be set so that failures occur in the specimens' outer fibers.

This is also asserted that this method of testing should be performed at least 5 times for a specific material before drawing conclusions. In the case of anisotropic materials, the test should be done in both the lengthwise and crosswise directions since the behavior differs.

Conditioning

To complete the test, the specimens should be kept at a temperature of 23+/-2°C and a relative humidity of 50+/-5 percent for at least 40 hours. These criteria also apply at the time of test execution.

Procedure A:

- For each measurement, use an untested specimen.

- As specified in item 10.1.1, record the width and depth of the specimen at the center of the support span.

- In the case of equipment with a continuously adjustable span, correctly measure the span as specified in 10.1.3. (This will be used for further calculations).

- Using the following equation, calculate the rate of crosshead motion:

$$R = ZL^2/6d$$

Where R is the rate of crosshead motion in millimeters per minute.

L=support span in mm

d=beam depth in mm

Z=rate of straining of the outer fiber in mm/mm/min (which should be equal to 0.01)

- Align the loading nose and supports such that the nose is in the middle of the supports.

- Load the specimen at the selected crosshead rate and use the data to generate the stressstrain curve. The deflection should be measured using either a gage placed beneath the specimen or by measuring the relative motion of the loading nose relative to the supports. There should be an area at the beginning of the curve termed the toe region, which does not reflect any material attribute and is created by slack take-up and specimen alignment or seating. This should be adjusted for by expanding the curve's linear part (CD), commonly known as the Hookean behavior.

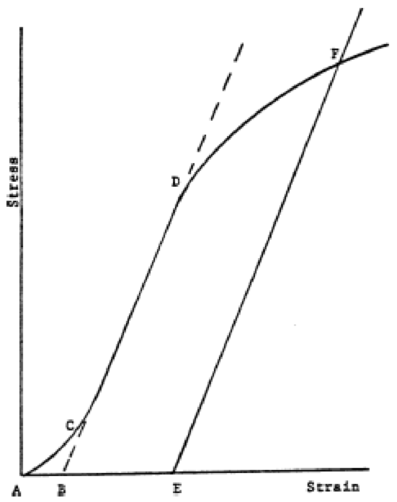

Fig.2 Hookean region

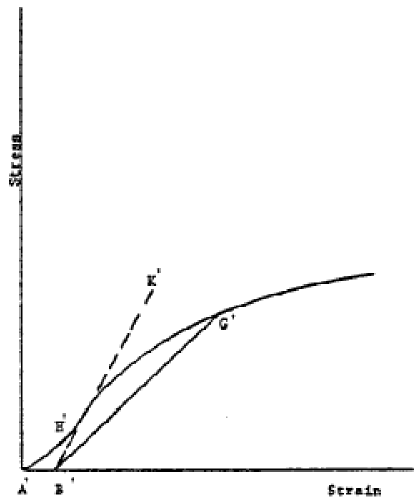

Fig.3 No Hookean region

If the material has not a linear section, the adjustment should be made by extending a tangent line from the point where the curve has the most slope.

- The test should be terminated when the maximum strain is attained or the specimen's outer surface breaks or fails.

Procedure B:

The sequence of execution for this procedure is the same as described previously, with the exception that the rate of straining of the test specimen is equal to 0.10 mm/mm/min.

Micro-cracking normally develops at around 0.2 percent strain in a polyester woven roving laminate, with final failure not occurring until 2.0 percent strain, according to experiments. To elaborate the test, selecting technique A may be sufficient. However, if the findings from this approach are not satisfactory, it may be a good idea to do the other process on at least one specimen.

Flexural Stress Calculation:

When a homogeneous elastic material is tested in flexure in the circumstances described in this report, the maximum stress occurs at the midpoint of the support span and may be computed at any position on the load-deflection curve using:

$$\sigma_f = 3PL/2bd^2$$

P = load at a specific position on the curve in N

L = support span in mm

b = width of beam tested in mm

d = depth of beam tested in mm

The offered equation is only correct for materials that exhibit elastic deformation to the point of rupture, and because this is not always the case, a minor mistake may be present when using the equation.

When the materials in question are highly orthotropic laminates, the maximum stress may not necessarily be situated on the specimen's outer surface, and it may be essential to employ laminated beam theory ideas to establish the tensile stress at failure.

If the Hookean material equation is used, it implies that homogeneous beam theory is used, which estimates apparent strength. The apparent strength of highly orthotropic laminates is strongly reliant on the ply-stacking sequence.

When the span-to-depth ratio is more than 16:1, another formula should be considered:

$$\sigma_f = (3PL/2bd^2)[1 + 6(D/L)^2 - 4(d/L)(D/L)]$$

Looking at the graph, one can see that there are several critical points of the curve that should be taken into account. The flexural strength (fM), for example, reflects the maximum flexural stress supported by the beam. In the event of materials that do not break before reaching a strain of 5%, the generated curve may have a zone where the stress does not rise with strain increase, which is a yield point.

The flexural stress at break (σfB), which can be seen in Curve a, is another important point of the curve.

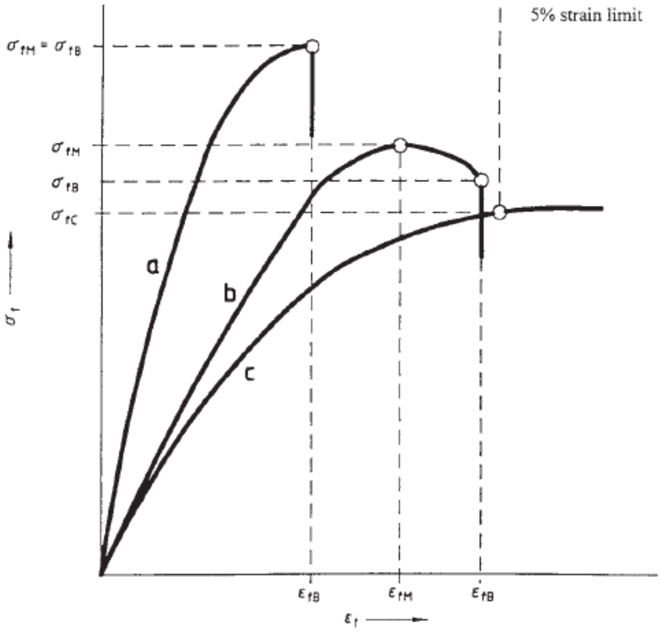

Fig.4 Common flexural stress versus flexural strain graph

The flexural stress may be calculated at any time in the experiment using the previous formulae.

The following equation may be used to calculate the flexural strain, which indicates the nominal fractional change in the length of the specimen's outer surface:

$$\epsilon_f = 6Dd/L^2$$

Where D is the greatest deflection of the beam's center in millimeters.

The equation's other parameters are the same as those in the previous equations. For this sort of material, the modulus of elasticity, which is a very significant characteristic to define, may be separated into three components: the Tangent Modulus of Elasticity (remaining to the elastic behavior of the material), the Secant Modulus, and the Chord Modulus.

1. Tangent Modulus of Elasticity – described as the ratio of stress to strain at any point in the first section of the curve (elastic regime) or may be derived for highly anisotropic composites using the following equation:

$$E_B = L^3 m / 4bd^3$$

With m that represent the slope of the curve

2. Secant Modulus of Elasticity – this one displays the stress-to-strain ratio for any chosen position on the curve (in N/mm2). It should always be registered with the point on the curve that was chosen for computation.

3. Chord Modulus – This value may be determined by taking into account two distinct points on the curve that can be chosen based on the material requirement or the customer contract.

$$E_f = (\sigma_{f2} - \sigma_{f1})/(\epsilon_{f2} - \epsilon_{f1})$$

Where $\sigma f1$ and $\sigma f2$ are the chosen places' stresses and 1 and 2 are the corresponding strains.

Because these tests should always be performed on several specimens, the arithmetic mean for each of the parameters indicated above should be determined in order to get average results. The standard deviation must also be determined.

Precision and bias

Because this type of calculation and experiment rely on the equipment used and the characteristics of the specimens, the only way to generalize the obtained results and estimate a proper value for a specific material is to collect the results obtained by a variety of laboratories that perform the tests as specified in ASTM D-790 (Table 1). To filter the values of the results, apply the same principles that were used in the burn-off test, which evaluate the repeatability and reproducibility of the findings, as described in subject 14.2.

The mixes rule

The Rules of Mixtures offer a simple but extremely practical approximation of stiffness for elastic qualities in terms of material properties. It is used to quickly and easily compute the elastic properties of composites. They are simulations of micromechanical systems. The Rule of Mixtures is a set of mathematical formulae that express composite qualities in terms of constituent properties, amount, and arrangement. It is based on simplifying assumptions, which are usually sufficient, particularly in the early phases of design or when more accurate test data is unavailable.

Fractions of density, volume, and weight:

$$\rho_C = \rho_f \, V_f + \rho_m \, V_m$$

$$\rho_C = \frac{1}{\left(\frac{W_r}{\rho_c}\right) + (\frac{W_m}{\rho_m})}$$

$$W_r = \frac{\rho_f}{\rho_c} \, V_r$$

$$W_m = \frac{\rho_m}{\rho_c} \, V_m$$

Stiffness along the length:

$$E = \eta_O \, \eta_L \, E_f \, V_f + \, E_m \, (1 - V_f)$$

η_L $\approx$ *1* (fibre length > *10 mm*);

η_O = 1 (UD), 0.5 (WR), 0.375 (CSM)

Transverse Stiffness:

$$\frac{1}{E_{cT}} = \frac{V_f}{E_f} + \frac{V_m}{E_m}$$

Shear Modulus:

$$\frac{1}{G_{LT}} = \frac{V_f}{G_f} + \frac{V_m}{G_m}$$

Poisson's Modulus:

$$\upsilon_{LT} = \upsilon_f \, V_f + \upsilon_m \, V_m$$

$$\frac{\upsilon_{LT}}{E_L} = \frac{\upsilon_{TL}}{E_T}$$

Conclusion

Including this study and the ASTM standard criteria for carrying out this sort of test illustrate, measuring the specimens needs a great deal of accuracy, and the equipment necessary must be extremely exact as well as types of ratios in order to achieve acceptable readings. In general, it is difficult to define the mechanical characteristics of composite materials as there are many aspects that must be taken into account to prevent generating findings that do not match reality. Although there are certain problems that must be overcome in order to obtain appropriate values for this sort of material, it is critical to do these types of studies since the stiffness of a laminate is typically tough to deal with.

Even though there are some challenges that must be overcome in order to obtain acceptable values for this type of material, it is critical to conduct these types of experiments because the strength of a laminate is typically difficult to work with in terms about how much load it can resist before it fails completely. Because they are not isotropic, cracks frequently appear just before laminate achieves the stress level of its ultimate strength. As a result, engineers must be aware of the regular service loads that can be decided to apply to these materials in order to ensure long-lasting structures made of this type of laminates.

References

- Document ‘’*Standard Test Method for Ignition Loss of Cured Reinforced Resins’’;*

- Document *‘’Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Eletrical Insultaing Materials’’.*

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- Veritas, B. (s.d..). *Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey;*