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# SIZING SINGLE CANTILEVER BEAM SPECIMENS FOR CHARACTERIZING FACESHEET/CORE PEEL DEBONDING IN SANDWICH STRUCTURE

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**Abstract.** *This paper details part of an effort focused on the development of a standardized facesheet/core peel debonding test procedure. The purpose of the test is to characterize facesheet/core peel in sandwich structure, accomplished through the measurement of the critical strain energy release rate associated with the debonding process. The specific test method selected for the standardized test procedure utilizes a single cantilever beam (SCB) specimen configuration. The objective of the current work is to develop a method for establishing SCB specimen dimensions. This is achieved by imposing specific limitations on specimen dimensions, with the objectives of promoting a linear elastic specimen response, and simplifying the data reduction method required for computing the critical strain energy release rate associated with debonding. The sizing method is also designed to be suitable for incorporation into a standardized test protocol. Preliminary application of the resulting sizing method yields practical specimen dimensions.*

## 1 INTRODUCTION

Facesheet/core debonding, which involves the separation of a facesheet from the core material in a sandwich structure, can threaten the structural integrity of a component [1]. As mode I-dominated debonding is thought to be the most critical debonding process in sandwich structure, the literature is populated with various test methods, geared towards the characterization of facesheet/core peel debonding [1-20]. All these tests involve the preparation of a sandwich beam with a debond running partially along one facesheet/core interface. The partially debonded facesheet is peeled from the core, and the corresponding critical strain energy release rate (referred to here as debond toughness) is measured. Although each of these tests exhibits slight differences relative to one another, they can be grouped into one of two general configurations. One of these configurations, illustrated in Fig. 1a, is based on a single cantilever beam (SCB) design, where a force is applied to the debonded facesheet, while the underside of the specimen is secured to a rigid, non-rotating base. The other configuration, illustrated in Fig. 1b, is based on a double cantilever beam (DCB) design, where equal and opposite forces are applied to the specimen, either side of the facesheet/core debond. A more detailed summary of the test methods introduced in Refs. 1-20 is contained in a previous article [21].

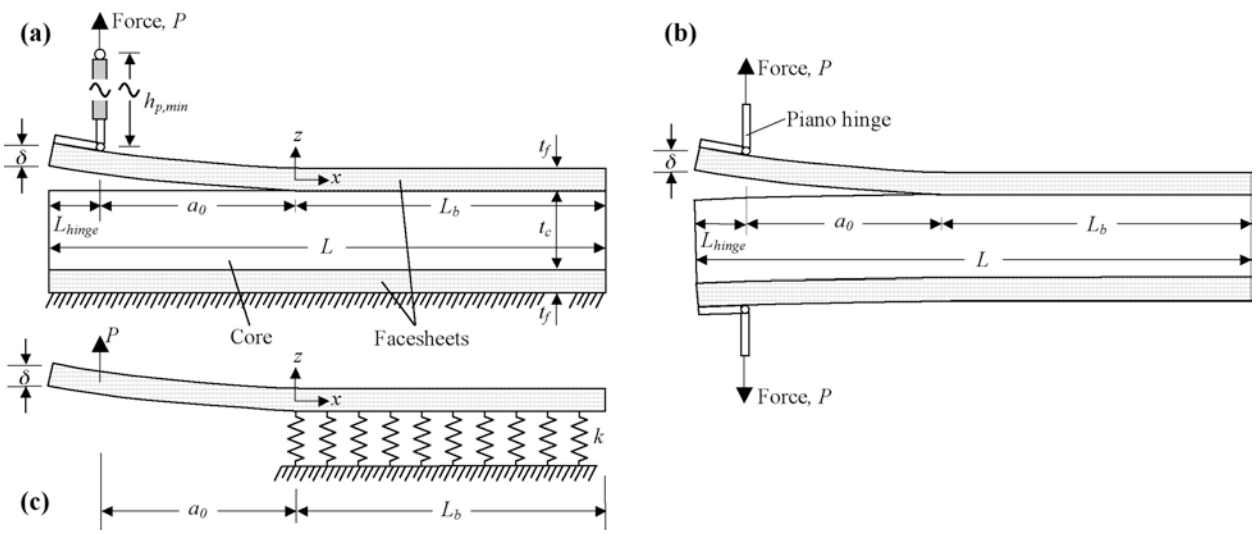


Figure 1 (a) Single cantilever beam configuration, (b) double cantilever beam configuration, (c) Beam-on-elastic foundation model of the single cantilever beam configuration.

Several of these aforementioned test methods have been used independently to characterize facesheet/core debonding in identical or similar sandwich systems. A recent comparison of these data highlighted significant scatter in reported debond toughness values for a given sandwich system [21]. The differing sources of these data make it difficult to pinpoint the exact reasons for the scatter, thus limiting the quantitative value of the data. Meanwhile, fracture mechanics-based tools are being made available in commercial finite element analysis codes, such as ABAQUS® /Standard, which enable simulation of processes such as delamination and facesheet/core debonding. The accuracy, however, of such simulations resides significantly with the reliability of fracture criteria, such as debond toughness in the case of facesheet/core peel, that are used in these fracture mechanics tools. Consequently, a clear motivation exists for establishing a standardized test procedure for characterizing facesheet/core peel debonding, capable of producing reliable values of debond toughness.

A recent evaluation of a number of these facesheet/core peel tests [20] indicated that the exact SCB specimen configuration illustrated in Fig. 1a would be appropriate for incorporation into a standardized testing procedure. The test is said to offer mode I-dominated loading conditions along the debond front, which are virtually independent of debond length. The test is also simple to perform, involving a straightforward loading apparatus, and a well-defined, simple data reduction method is used for computing debond toughness from the test data [20]. These are all attributes that render the SCB specimen suitable for standardization. However, an appropriate protocol for conducting this test as part of a standardized test procedure has yet to be established. Therefore, the objective of the current work is to begin the protocol development by establishing a systematic method for determining appropriate dimensions of the SCB specimen.

This paper includes the following sections. Section 2 contains a description of the SCB test. Section 3 summarizes a sample set of sandwich systems that will be applied to the SCB specimen sizing method developed in Section 4. The resulting specimen dimensions are discussed in Section 5, followed by a summary of this work in Section 6.

## 2 SINGLE CANTILEVER BEAM SPECIMEN TEST

The SCB specimen test has been shown recently to be the most promising candidate, amongst those available in the literature, for development into a standardized test protocol [20]. This is mainly due to the simplicity of the SCB test procedure and data reduction method. Further discussion, focused on the requirements of a standardized test method, and how the SCB specimen test satisfies these requirements is contained in a previous article [21]. In this section, the SCB specimen test is described.

A schematic of the SCB specimen is illustrated in Fig. 1a. A number of differing versions of this specimen have been independently proposed in the literature [1,2,5,8,20]. The overall purpose of the test is to measure the static debond toughness associated with a facesheet peeling from the core of a sandwich beam. The general test procedure is analogous to that used for characterizing mode I delamination resistance in composite laminates, as employed in ASTM International Test Method D5528-01© [22]. In the SCB test, a sandwich beam is prepared with a facesheet/core debond of initial length, $a_0$, at one interface (see Fig. 1a). The specimen is loaded under displacement control (at a quasi-static displacement rate) until the debond is grown to a certain length, $a_0+a_{prop}$, after which the specimen is unloaded. The applied force is vertically offset from the specimen by height, $h_{p,min}$ (Fig. 1a), to ensure that the loading direction remains essentially vertical during a test. This serves to prevent shear loading along the debond front, which occurs when the load point rotates. Applied force, $P$, and corresponding load-point displacement values, $\delta$, are recorded at several increments of debond growth, as shown in the force-displacement response illustrated in Fig. 2a. The corresponding specimen compliance, $C$, is then calculated at each debond growth increment using the relationship, $C=\delta/P$. This method for calculating specimen compliance is therefore only valid for specimens that respond in a linear elastic manner. Furthermore, if machine compliance is suspected to be significant, this must be subtracted from the compliance values measured during the SCB test. Machine compliance is typically measured by testing a rigid, replica specimen. Linear elastic fracture mechanics (LEFM) is used to compute the debond toughness, $G_c$, from the following relation [23]:

$$G_c = \frac{P_c^2}{2b}\frac{dC}{da} \tag{1}$$

where $P_c$ is the force at the onset of debond growth, and $b$ is the specimen width. The derivative,

$dC/da$, is evaluated from the compliance/debond length relationship recorded during the test. Previous investigations using this SCB specimen, and other specimen configurations, have made use of the following form for this relationship [6,7,17]:

$$C_{SCB} = m(a + \Delta)^3 \tag{2}$$

where the parameters $m$ and $\Delta$ are dependent on the sandwich system tested, and are evaluated from the relationship between $C^{1/3}$ and debond length, $a$, as illustrated in Fig. 2b. Substituting Eq. 2 into Eq. 1 for $dC/da$ gives the expression used for calculating $G_c$:

$$G_c = \frac{3P_c\delta_c}{2b(a + |\Delta|)} \tag{3}$$

where $\delta_c$ is the load-point displacement at the onset of debond growth. Values of debond toughness are computed for each debond length increment, at which specimen compliance was measured, thus establishing the relationship between debond toughness and debond length. This relationship is analogous to an R-curve measured from DCB [22] tests conducted on monolithic laminates.

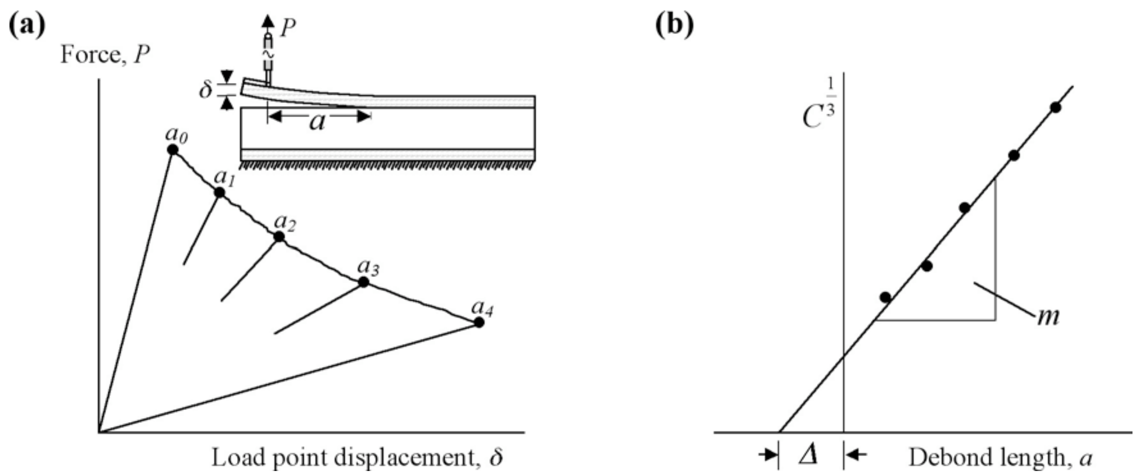


Figure 2 (a) Illustrative force-displacement response of a SCB specimen, (b) Method used to determine compliance parameters, $m$ and $\Delta$.

Although previous work has indicated that this test is a likely candidate for standardization [20], the validity of the data reduction method proposed for use with this test relies upon the SCB specimen dimensions, and other test parameters, being kept within specific limits. As will be shown in Section 4, these limitations form the basis of a method for determining appropriate SCB specimen dimensions. In the following section, a range of sandwich systems thought likely to be applied to the SCB test are described. The specimen sizing procedure detailed in Section 4 will be applied to these sandwich systems, to evaluate whether the method yields specimen dimensions practical for testing. This study is discussed in Section 5.

## 3 SANDWICH SYSTEMS

The range of sandwich systems considered here stems from four classes of facesheet and core material systems, which are thought to be representative of materials commonly used in panels for the marine and aerospace industries. The four classes of facesheet material systems include fiber reinforced/epoxy tape and plain weave fabric, with either carbon or glass used for the fiber reinforcement. Furthermore, only tape and plain weave fabric facesheets consisting of a unidirectional stacking sequence, with principle fiber direction parallel to SCB specimen length, are considered in the current work. This is to avoid unwanted energy dissipating mechanisms during a SCB test, from sources such as matrix cracking in off-axis plies. Subsequently, the sizing method developed in Section 4 will only be appropriate for sandwich construction with unidirectional facesheets. The implications of this limitation are expanded upon in Section 4.3.

The four classes of core material considered here include end grain balsa wood, PVC foam, aluminum honeycomb, and Nomex® honeycomb. Each of these materials is offered in a range of densities and thicknesses (thickness direction corresponding to z-axis in Fig. 1a). Thus, four versions of each core material type will be considered, corresponding to the lowest and highest densities offered, with two core thickness values of 12.5mm and 50mm, considered for each density. Subsequently, a total of 64 sandwich systems will be considered.

The properties of the facesheet and core materials, pertinent to the specimen sizing procedure, are presented in Table 1. The facesheet properties are averaged values of five individual systems of each class, where $E_f$ and $G_{xz,f}$ are the flexural and shear moduli, respectively (relative to the coordinate system in Fig. 1a). The parameter, $\sigma_c$, is a bending stress allowable that may be experienced by the facesheet without flexural failure. A complete description of these data is available in Ref. 21. The core material property, $E_c$, is the thickness-direction modulus, taken from the respective manufacturers data sheets [24,25]. The property, $G_c$, is the assumed facesheet/core peel debond toughness of a sandwich system consisting of the corresponding core material. For instance, any sandwich system consisting of H45 PVC foam will be assumed to exhibit a debond toughness of 0.35kJ/m$^2$. These data are based on average debond toughness values reported for sandwich configurations containing similar core materials [21]. A description of the origin of the data in Table 1 is presented in Ref. 21.

| **Facesheet material system** | $E_f$ **MPa** | $G_{xz,f}$ **MPa** | $\sigma_c$ **MP** | **Core material system** | **Density kg/m$^3$** | $E_c$ **MPa** | $G_c$ **kJ/m$^2$** |
|---|---|---|---|---|---|---|---|
| Carbon/epoxy tape | 137000 | 5000 | 1090 | End grain balsa wood | 90 | 1850 | 0.84 |
| Carbon/epoxy plain weave fabric | 65000 | 4000 | 470 | End grain balsa wood | 220 | 6840 | 0.84 |
| Glass/epoxy tape | 46000 | 4000 | 800 | H45 PVC foam | 45 | 30 | 0.35 |
| Glass/epoxy plain weave fabric | 25000 | 3500 | 225 | H200 PVC foam | 200 | 440 | 1.13 |
| | | | | Aluminum honeycomb | 16 | 70 | 1.6 |
| | | | | Aluminum honeycomb | 192 | 4480 | 1.6 |
| | | | | Nomex® honeycomb | 24 | 41 | 0.96 |
| | | | | Nomex® honeycomb | 128 | 414 | 1.42 |

Table 1 Properties of unidirectional facesheet material systems and core materials considered in the present study

## 4 SCB SPECIMEN SIZING PROCEDURE

The validity of fitting compliance/debond length data from SCB tests to the form shown in Eq. 2 has not been fully established. Additionally, no method exists to ensure that the SCB specimen will respond in a linear elastic manner during a test. Subsequently, a method is developed in this section that offers a means for establishing SCB dimensions for a given sandwich system, that will ensure the specimen meets these conditions. The starting point of this method uses a closed-form compliance solution (compliance/debond length relationship) developed by Li and Carlsson [9], which can be applied to the SCB specimen. The method then proceeds by imposing specific limitations on several specimen dimensions that simplifies the compliance solution to the form shown in Eq. 2, and promotes a linear elastic response from the SCB specimen. This technique is an extension of a method developed by Li and Carlsson, used to establish specimen length and debond length of tilted sandwich debond (TSD) specimens [9]. The resulting method, described at the end of this section (Section 4.3), provides a means for establishing the following dimensions of a SCB specimen made from any sandwich system (Fig. 1a):

| | |
|---|---|
| $a_0$ | Initial debond length (debond length at beginning of test) |
| $a_{max}$ | Maximum debond length |
| $L_{min}$ | Minimum specimen length |
| $t_f$ | Facesheet thickness |
| $h_{p,min}$ | Load rod length |

### 4.1 SCB specimen compliance solution

The SCB specimen is modeled as a cantilever beam partially supported by an elastic foundation, as illustrated in Fig. 1c. The beam consists of two sections. The first section, corresponding to the unbonded portion of the SCB specimen facesheet, is considered to be free of the elastic foundation. The second section, corresponding to the intact portion of the SCB specimen facesheet, is supported by an elastic foundation. The elastic foundation is included to model the thickness-direction elastic response of the core material (z-axis in Fig. 1c). The two sections of the beam connect at the location corresponding to the tip of the facesheet/core debond, which corresponds to the origin of the coordinate system used in the analysis. Use of this type of model for the development of compliance solutions of fracture specimens was first employed by Kanninen, for an analysis of a metal double cantilever beam specimen [26]. Li and Carlsson [9] applied Kanninen's model to the tilted sandwich debond (TSD) specimen. Their solution for the TSD specimen at zero tilt angle (which equates to the SCB specimen) is used here for the compliance solution of the SCB specimen, and is expressed as [9]:

$$C_{SCB} = \frac{\delta}{P} = \frac{4\lambda}{k}\left[\frac{\lambda^3 a^3}{3} + \lambda^2 a^2 F_1 + \lambda a F_2 + \frac{3ak}{10\lambda G_{xz,f} t_f b} + \frac{F_3}{2}\right] \tag{4}$$

The parameters $t_f$, $b$, and $G_{xz,f}$ are the facesheet thickness, SCB specimen width, and facesheet shear modulus, respectively (subscripts relate to coordinate system in Fig. 1c). The compliance coefficients, $F_1$, $F_2$, and $F_3$ are hyperbolic functions, which reduce to unity, providing the intact SCB specimen length, $L_b$, (Fig. 1a) is kept above a minimum value, $L_{b,min}$. The parameter, $k$, is the elastic foundation modulus, and is related to the z-direction modulus of the core material as follows [26]:

$$k = \frac{E_c b}{t_c} \tag{5}$$

where the parameters $t_c$ and $E_c$ are the thickness and z-direction modulus of the core, respectively. The parameter, $\lambda$, is effectively the ratio of the stiffness of the elastic foundation to the bending stiffness of the beam, and is given by [9]:

$$\lambda = \left[\frac{3k}{E_f t_f^3 b}\right]^{\frac{1}{4}} = \left[\frac{3E_c}{t_c t_f^3 E_f}\right]^{\frac{1}{4}} \tag{6}$$

A complete derivation of Eq. 4 and the relations in Eqs. 5 and 6 can be found in Ref. 9. The compliance solution in Eq. 4 clearly differs from the form shown in Eq. 2. In the proceeding section, limitations imposed on SCB specimen dimensions and other test parameters, are discussed that reduce Eq. 4 to the form of Eq. 2, and also act to promote a linear elastic response from an SCB specimen.

## 4.2 Imposed SCB specimen limits

The compliance solution of the SCB specimen in Eq. 4 can be simplified to the form shown in Eq. 2 by imposing the limitations on minimum intact specimen length, $L_{b,min}$, and initial debond length, $a_0$, which are summarized in Table 2. With these limitations imposed, the SCB specimen compliance solution, Eq. 4, reduces to the form in Eq. 2, in this case written as:

$$C_{SCB} = \frac{4}{E_f b t_f^3}\left[a + \frac{1}{\lambda}\right]^3 \tag{7}$$

| | SCB Specimen Parameter | Limitation |
|---|---|---|
| **1** | Specimen width | $b \geq 25$mm or six honeycomb cell sizes |
| **2** | Minimum intact specimen length to ensure $F_1$, $F_2$, and $F_3$ remain at unity | $L_{b,min} \geq 2.7\left[\frac{t_c t_f^3 E_f}{3E_c}\right]^{\frac{1}{4}}$ |
| **3** | Initial debond length to ensure bending is dominant deformation mode of facesheet | $a_0 \geq a_{min}^{bending} \approx \sqrt{\frac{30E_f t_f^2}{G_{xz,f}}} - 0.59L_{b,min}$ |
| **4** | Initial debond length to ensure compliance adopts the form of Eq. 2 | $a_0 \geq a_{min}^{compliance} = L_{b,min}$ |
| **5** | Final debond length to ensure a required amount of debond growth, $a_{prop}$ | $a_{max} \geq a_0 + a_{prop}$, where $a_{prop} = 50$ or $80mm$ [21] |
| **6** | Minimum facesheet thickness to assume small deformation in linear analysis | $t_f \geq t_f^{small\ disp} = \left[\frac{a_{max}}{\left(\frac{3a_{max}^2 E_f}{200G_c}\right)^{\frac{1}{4}} - \left(\frac{t_c E_f}{3E_c}\right)^{\frac{1}{4}}}\right]^{\frac{4}{3}}$ |
| **7** | Minimum facesheet thickness to prevent flexural failure of facesheet | $t_f \geq t_f^{strength} \approx \frac{6E_f G_c a_{max}^2}{\sigma_c^2}\left[a_{max} + \left(\frac{t_c (t_f^{small\ disp})^3 E_f}{3E_c}\right)^{\frac{1}{4}}\right]^{-2}$ |
| **8** | Minimum specimen length | $L_{min} \geq L_{hinge} + a_{max} + L_{b,min}$ |
| **9** | Minimum load application offset to ensure vertical load application | $h_{p,min} \approx 1.062a_{max}$ |

Table 2 Summary of SCB specimen Limitations

Maximum facesheet thickness is calculated by adding the required amount of debond growth, $a_{prop}$, to the initial debond length, $a_0$. Where $a_0$ is the largest of the two values computed using Limitations 3 and 4 in Table 2. A value of $a_{prop}$ is chosen to ensure a sufficient number of debond growth increments are recorded for performing the data reduction procedure described in Section 2. During a summary of previous tests, previous work [21] reported that a sufficient value for $a_{prop}$ is 50mm when debond growth is stable, and 80mm when debonding behaves in a stick-slip manner, where growth takes place in discrete spurts. Facesheet thickness is limited to a minimum value to ensure that the SCB specimen responds in a linear elastic manner (including avoidance of failure), and in accordance with beam theory. Minimum specimen length is computed as the sum of the length required for the piano hinge, $L_{hinge}$, maximum debond length, $a_{max}$, and minimum intact specimen length, $L_{b,min}$. The minimum load-point offset is also calculated (Length $h_{p,min}$ in Fig. 1a) to ensure load application remains essentially vertical during a SCB test.

As can be seen from the summary of these limitations in Table 2, more than one limitation is imposed on initial debond length and facesheet thickness. Furthermore, the in-plane specimen dimensions are dependant on facesheet thickness. Subsequently, the iterative procedure described next in Section 4.3 is required to determine all specimen parameters. A complete derivation of the nine limitations summarized in Table 2 is presented in Ref. 21.

### 4.3 Calculating SCB specimen dimensions

The following procedure is developed on the basis of the SCB specimen test limitations summarized in Table 2. This procedure offers a systematic approach for determining appropriate dimensions of an SCB specimen, based on any sandwich system (assuming unidirectional tape or plain weave fabric facesheets). The procedure should be well-suited to incorporation into a standardized testing protocol due to the simple computations involved. The procedure is conducted as follows:

1. Select values of $L_{hinge}$, $t_c$, $E_c$, $G_{xz,f}$, $E_f$, $G_c$, $a_{prop}$, $\sigma_c$, and initial value of $t_f$.
2. Limitation 1: Determine specimen width, $b$
3. Limitation 2: Compute the minimum intact specimen length, $L_{b,min}$.
4. Limitation 3: Compute initial debond length to ensure bending is the dominant deformation mode of the loaded facesheet, $a_{min}^{bending}$.
5. Limitation 4: Compute initial debond length for simplifying the compliance solution: $a_{min}^{compliance}$.
6. Select $a_0$ (largest of the two values, $a_{min}^{bending}$ and $a_{min}^{compliance}$).
7. Limitation 5: Compute maximum debond length, $a_{max}$.
8. Limitation 6: Compute minimum facesheet thickness to ensure assumption of small displacements is valid, $t_f^{small\ disp}$.
9. Limitation 7: Compute minimum facesheet thickness necessary to prevent facesheet arm failure, $t_f^{strength}$.
10. Select $t_{f,min}$ (largest of the two values, $t_f^{small\ disp}$ and $t_f^{strength}$). If $t_{f,min}$ is greater than the initial value selected in Step 1, repeat Steps 3-9 with $t_f = t_{f,min}$. Otherwise, set $t_f = t_{f,min}$ and proceed to Step 11.

11. Limitations 8 and 9: Compute minimum specimen length, $L_{min}$, and loading rod length, $h_{p,min}$.
12. The resulting SCB specimen dimensions are therefore, $b$, $t_{f,min}$, $a_0$, $a_{max}$, and $L_{min}$, and $h_{p,min}$.

The above procedure assumes that sandwich panels will be manufactured to the computed dimensions. Furthermore, the procedure is aimed at specimens that contain unidirectional facesheets, where fiber direction is parallel to specimen length. However, it may often be desirable to test specimens from existing sandwich panels, which contain non-unidirectional facesheets. In such cases, the specimen sizing procedure may be used to establish the in-plane dimensions of the SCB specimens, however, these specimens may exhibit unwanted energy dissipating mechanisms from potential damage in susceptible plies, such as those oriented away from the specimen length direction. Therefore, debond toughness data from tests conducted on specimens taken from pre-manufactured panels should be treated only as qualitative values. In such cases, the flexural modulus of the non-unidirectional facesheet, $E_f$, must first be established, either through direct measurement [27], or through a laminated plate theory computation [28]. Steps 1-7, and 11 of the sizing procedure would then be used to establish the in-plane dimensions of the SCB specimens.

## 5 COMPUTED SCB SPECIMEN DIMENSIONS

The method summarized in Section 4.3 was applied to the 64 sandwich systems discussed previously in Section 3. The computed SCB specimen dimensions of all 64 sandwich systems considered in this study are presented in Tables 3 and 4 ($b$=25mm and $L_{hinge}$=25.4mm in all cases). The data are meant to act as a quick guide for estimating SCB specimen dimensions for a given sandwich system.

It is observed in general that the sizing procedure yields very practical specimen dimensions for the cases considered. Though, it is noted that only tape and plain weave fabric facesheets, with a unidirectional stacking sequence and principal fiber direction oriented parallel to specimen length, are considered. The following general observations of the computed specimen dimensions presented in Tables 3 and 4 are made (note that quoted limitation numbers correspond to those summarized in Table 2):

- Minimum intact specimen length (Limitation 2) is always equal to the initial debond length, when initial debond length is governed by the compliance solution simplification limitation (Limitation 4).
- Minimum intact specimen length is constant for a given core material and core thickness, regardless of facesheet material.
- Initial debond length is governed by the bending deformation limitation (Limitation 3) in approximately half of the cases considered. In the other cases, initial debond length is governed by the compliance solution simplification limitation (Limitation 4).
- Facesheet thickness is governed by the small displacement limitation in all cases considered (Limitation 6).
- Facesheet thickness increases with an increase in core thickness, for a given core material.
- Computed facesheet thickness varies from 1.65mm to 6.54mm, suggesting that facesheets of practical thickness result from the current sizing procedure.

- Computed specimen lengths range from 160mm to 301mm, suggesting that practical specimen length values result from the current sizing procedure.
- Computed loading rod lengths range from 121mm to 188mm, suggesting that this load application method will be practical for use. Loading rod length is in direct proportion with $a_{max}$.

| **Sandwich System (facesheet / core)** | $t_c$ | $t_f$ **mm** | $L_{b,min}$ **mm** | $a_0$ **mm** | * | $a_{max}$ **mm** | $L_{min}$ **mm** | $h_{p,min}$ **mm** |
|---|---|---|---|---|---|---|---|---|
| Carbon/epoxy tape / balsa (90kg/m$^3$) | 12.5 | 2.01 | 19 | 46 | b | 126 | 171 | 134 |
| Carbon/epoxy fabric / balsa (90kg/m$^3$) | 12.5 | 2.56 | 19 | 45 | b | 125 | 170 | 133 |
| Glass/epoxy tape / balsa (90kg/m$^3$) | 12.5 | 2.82 | 19 | 41 | b | 121 | 165 | 129 |
| Glass/epoxy fabric / balsa (90kg/m$^3$) | 12.5 | 3.41 | 19 | 39 | b | 119 | 163 | 126 |
| Carbon/epoxy tape / balsa (90kg/m$^3$) | 50 | 2.03 | 27 | 42 | b | 122 | 175 | 130 |
| Carbon/epoxy fabric / balsa (90kg/m$^3$) | 50 | 2.59 | 27 | 41 | b | 121 | 174 | 129 |
| Glass/epoxy tape / balsa (90kg/m$^3$) | 50 | 2.85 | 27 | 37 | b | 117 | 169 | 124 |
| Glass/epoxy fabric / balsa (90kg/m$^3$) | 50 | 3.45 | 27 | 35 | b | 115 | 167 | 122 |
| Carbon/epoxy tape / balsa (220kg/m$^3$) | 12.5 | 2 | 14 | 49 | b | 129 | 168 | 137 |
| Carbon/epoxy fabric / balsa (220kg/m$^3$) | 12.5 | 2.55 | 14 | 48 | b | 128 | 167 | 136 |
| Glass/epoxy tape / balsa (220kg/m$^3$) | 12.5 | 2.8 | 13 | 44 | b | 124 | 163 | 132 |
| Glass/epoxy fabric / balsa (220kg/m$^3$) | 12.5 | 3.39 | 13 | 42 | b | 122 | 160 | 129 |
| Carbon/epoxy tape / balsa (220kg/m$^3$) | 50 | 2.01 | 20 | 46 | b | 126 | 171 | 134 |
| Carbon/epoxy fabric / balsa (220kg/m$^3$) | 50 | 2.56 | 19 | 45 | b | 125 | 170 | 133 |
| Glass/epoxy tape / balsa (220kg/m$^3$) | 50 | 2.82 | 19 | 41 | b | 121 | 166 | 129 |
| Glass/epoxy fabric / balsa (220kg/m$^3$) | 50 | 3.41 | 19 | 39 | b | 119 | 163 | 126 |
| Carbon/epoxy tape / H45 PVC foam | 12.5 | 1.65 | 46 | 46 | c | 126 | 198 | 134 |
| Carbon/epoxy fabric / H45 PVC foam | 12.5 | 2.12 | 46 | 46 | c | 126 | 198 | 134 |
| Glass/epoxy tape / H45 PVC foam | 12.5 | 2.38 | 46 | 46 | c | 126 | 198 | 134 |
| Glass/epoxy fabric / H45 PVC foam | 12.5 | 2.91 | 46 | 46 | c | 126 | 198 | 134 |
| Carbon/epoxy tape / H45 PVC foam | 50 | 2 | 75 | 75 | c | 155 | 256 | 165 |
| Carbon/epoxy fabric / H45 PVC foam | 50 | 2.56 | 75 | 75 | c | 155 | 256 | 165 |
| Glass/epoxy tape / H45 PVC foam | 50 | 2.87 | 75 | 75 | c | 155 | 256 | 165 |
| Glass/epoxy fabric / H45 PVC foam | 50 | 3.52 | 75 | 75 | c | 155 | 256 | 165 |
| Carbon/epoxy tape / H200 PVC foam | 12.5 | 2.34 | 31 | 49 | b | 129 | 185 | 137 |
| Carbon/epoxy fabric / H200 PVC foam | 12.5 | 2.98 | 31 | 48 | b | 128 | 184 | 136 |
| Glass/epoxy tape / H200 PVC foam | 12.5 | 3.27 | 30 | 43 | b | 123 | 178 | 131 |
| Glass/epoxy fabric / H200 PVC foam | 12.5 | 3.96 | 30 | 40 | b | 120 | 175 | 128 |
| Carbon/epoxy tape / H200 PVC foam | 50 | 2.41 | 44 | 44 | c | 124 | 194 | 132 |
| Carbon/epoxy fabric / H200 PVC foam | 50 | 3.09 | 44 | 44 | c | 124 | 194 | 132 |
| Glass/epoxy tape / H200 PVC foam | 50 | 3.46 | 44 | 44 | c | 124 | 194 | 132 |
| Glass/epoxy fabric / H200 PVC foam | 50 | 4.24 | 44 | 44 | c | 124 | 194 | 132 |

* Initial debond length governed by: (b) Limitation 3, (c) Limitation 4

Table 3 Computed SCB specimen dimensions

| **Sandwich System (facesheet / core)** | $t_c$ **mm** | $t_f$ **mm** | $L_{b,min}$ **mm** | $\underline{a_0}$ **mm** | * | $a_{max}$ **mm** | $L_{min}$ **mm** | $h_{p,min}$ **mm** |
|---|---|---|---|---|---|---|---|---|
| Carbon/epoxy tape / AL hcomb ($16kg/m^3$) | 12.5 | 2.98 | 58 | 58 | c | 138 | 222 | 147 |
| Carbon/epoxy fabric / AL hcomb ($16kg/m^3$) | 12.5 | 3.83 | 58 | 58 | c | 138 | 222 | 147 |
| Glass/epoxy tape / AL hcomb ($16kg/m^3$) | 12.5 | 4.29 | 58 | 58 | c | 138 | 222 | 147 |
| Glass/epoxy fabric / AL hcomb ($16kg/m^3$) | 12.5 | 5.26 | 58 | 58 | c | 138 | 222 | 147 |
| Carbon/epoxy tape / AL hcomb ($16kg/m^3$) | 50 | 3.71 | 97 | 97 | c | 177 | 299 | 188 |
| Carbon/epoxy fabric / AL hcomb ($16kg/m^3$) | 50 | 4.76 | 97 | 97 | c | 177 | 299 | 188 |
| Glass/epoxy tape / AL hcomb ($16kg/m^3$) | 50 | 5.34 | 97 | 97 | c | 177 | 299 | 188 |
| Glass/epoxy fabric / AL hcomb ($16kg/m^3$) | 50 | 6.54 | 97 | 97 | c | 177 | 299 | 188 |
| Carbon/epoxy tape / AL hcomb ($192kg/m^3$) | 12.5 | 2.73 | 19 | 67 | b | 147 | 191 | 156 |
| Carbon/epoxy fabric / AL hcomb ($192kg/m^3$) | 12.5 | 3.48 | 19 | 65 | b | 145 | 190 | 154 |
| Glass/epoxy tape / AL hcomb ($192kg/m^3$) | 12.5 | 3.8 | 19 | 59 | b | 139 | 184 | 148 |
| Glass/epoxy fabric / AL hcomb ($192kg/m^3$) | 12.5 | 4.58 | 19 | 56 | b | 136 | 180 | 145 |
| Carbon/epoxy tape / AL hcomb ($192kg/m^3$) | 50 | 2.75 | 27 | 63 | b | 143 | 196 | 152 |
| Carbon/epoxy fabric / AL hcomb ($192kg/m^3$) | 50 | 3.51 | 27 | 61 | b | 141 | 194 | 150 |
| Glass/epoxy tape / AL hcomb ($192kg/m^3$) | 50 | 3.83 | 27 | 55 | b | 135 | 188 | 144 |
| Glass/epoxy fabric / AL hcomb ($192kg/m^3$) | 50 | 4.63 | 27 | 52 | b | 132 | 184 | 140 |
| Carbon/epoxy tape / Nomex® hcomb ($24kg/m^3$) | 12.5 | 2.53 | 59 | 59 | c | 139 | 223 | 147 |
| Carbon/epoxy fabric / Nomex® hcomb ($24kg/m^3$) | 12.5 | 3.24 | 59 | 59 | c | 139 | 223 | 147 |
| Glass/epoxy tape / Nomex® hcomb ($24kg/m^3$) | 12.5 | 3.63 | 59 | 59 | c | 139 | 223 | 147 |
| Glass/epoxy fabric / Nomex® hcomb ($24kg/m^3$) | 12.5 | 4.45 | 59 | 59 | c | 139 | 223 | 147 |
| Carbon/epoxy tape / Nomex® hcomb ($24kg/m^3$) | 50 | 3.14 | 98 | 98 | c | 178 | 301 | 189 |
| Carbon/epoxy fabric / Nomex® hcomb ($24kg/m^3$) | 50 | 4.03 | 98 | 98 | c | 178 | 301 | 189 |
| Glass/epoxy tape / Nomex® hcomb ($24kg/m^3$) | 50 | 4.52 | 98 | 98 | c | 178 | 301 | 189 |
| Glass/epoxy fabric / Nomex® hcomb ($24kg/m^3$) | 50 | 5.54 | 98 | 98 | c | 178 | 301 | 189 |
| Carbon/epoxy tape / Nomex® hcomb ($128kg/m^3$) | 12.5 | 2.62 | 34 | 55 | b | 135 | 194 | 143 |
| Carbon/epoxy fabric / Nomex® hcomb ($128kg/m^3$) | 12.5 | 3.34 | 34 | 54 | b | 134 | 193 | 142 |
| Glass/epoxy tape / Nomex® hcomb ($128kg/m^3$) | 12.5 | 3.65 | 33 | 48 | b | 128 | 187 | 136 |
| Glass/epoxy fabric / Nomex® hcomb ($128kg/m^3$) | 12.5 | 4.41 | 33 | 45 | b | 125 | 183 | 133 |
| Carbon/epoxy tape / Nomex® hcomb ($128kg/m^3$) | 50 | 2.69 | 49 | 49 | c | 129 | 203 | 137 |
| Carbon/epoxy fabric / Nomex® hcomb ($128kg/m^3$) | 50 | 3.44 | 49 | 49 | c | 129 | 203 | 137 |
| Glass/epoxy tape / Nomex® hcomb ($128kg/m^3$) | 50 | 3.87 | 49 | 49 | c | 129 | 203 | 137 |
| Glass/epoxy fabric / Nomex® hcomb ($128kg/m^3$) | 50 | 4.74 | 49 | 49 | c | 129 | 203 | 137 |

* Initial debond length governed by: (b) Limitation 3, (c) Limitation 4

Table 4 Computed SCB specimen dimensions

## 6 SUMMARY

With the introduction of fracture mechanics-based tools in commercial finite element analysis codes, the means for simulating damage events, such as facesheet/core debonding in sandwich structure, is becoming readily available. The accuracy, however, of such simulations resides significantly with the reliability of fracture criteria, such as the critical strain energy release rate (debond toughness), that are used in these fracture mechanics tools. Meanwhile, a search of the literature revealed that a large number of test methods have been proposed for characterizing facesheet/core debonding in sandwich structure. However, debond toughness data reported from a number of these tests conducted on similar sandwich systems, exhibit a significant amount of scatter. Subsequently, the SCB specimen has been identified as a candidate for standardizing the measurement of facesheet/core debond toughness. In the current work, an analytical treatment of the SCB specimen was used in the development of a procedure for determining appropriate dimensions of a SCB specimen. The procedure aimed to result in specimens that respond in a linear elastic manner, and exhibit a well-defined compliance/debond length relationship, that is easily adapted to a data reduction method for computing debond toughness. The sizing procedure was applied to 64 different hypothetical sandwich systems consisting of unidirectional facesheets, deemed to be representative of systems used in the marine and aerospace industries. Results from this study indicate that the sizing procedure should yield practical SCB specimen dimensions. This method for sizing SCB specimens should be well-suited for incorporation into a standardized testing protocol.

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