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Standard Practice for Fiber Reinforcement Orientation Codes for Composite Materials[1]

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1. Scope

1.1 This practice establishes orientation codes for continuous-fiber-reinforced composite materials. Orientation codes are explicitly provided for two-dimensional laminates and braids. The laminate code may also be used for filament-wound materials. A method is included for presenting subscript information in computerized formats that do not permit subscript notation.

2. Referenced Documents

2.1 *ASTM Standards:*

D 3878 Terminology of High-Modulus Reinforcing Fibers and Their Composites[2]

E 1309 Guide for Identification of Composite Materials in Computerized Material Property Databases[2]

2.2 *Other Documents:*

MIL-HDBK-17-2D, *Polymer Matrix Composites*, Vol 2 Materials Properties, Section 1.6.1[3]

ISO 1268-1 *Fibre-reinforced plastics—Methods of producing test plates—Part 1: General Conditions*, Annex Stacking Designation Systems[4]

3. Terminology

3.1 *Definitions*—Definitions in accordance with Terminology D 3878 shall be used where applicable.

4. Significance and Use

4.1 The purpose of a laminate orientation code is to provide a simple, easily understood method of describing the lay-up of a laminate. The laminate orientation code is based largely on a combination of industry practice and the codes used in the *NASA/DOD Advanced Composites Design Guide*,[5] MIL-HDBK-17, and ISO 1268-1.

4.2 The braiding orientation code provides similar information for a two-dimensional braid, based largely on *Standard Test Methods for Textile Composites*.[6]

5. Reference System

5.1 A reference plane and direction are selected before writing the orientation code. The reference plane is selected as the bottom or top layer for the laminate orientation code. For laminates symmetric about their midplane, the orientation code using the top layer as the reference plane is identical to the orientation code using the bottom layer as the reference plane; selection of the reference plane effectively determines the positive *z*- or three-axis of the laminate. The reference direction (0°) is somewhat arbitrarily selected for convenience and relevance to the application. Often, a dominant fiber direction is defined to be 0°. An example in which relevance to testing determines the reference direction is in-plane shear specimens in which the loading direction is selected as 0°.

6. Laminate Orientation (Lay-up) Code

6.1 The following information and the examples in Fig. 1 describe the laminate orientation code. Ply directions and number of layers are indicated using the laminate orientation code as follows:

$$[\theta_1 m_1 b_1 / \theta_2 m_2 b_2 \ \ldots]_{nsb} \text{ notes} \tag{1}$$

where:

θ_1, θ_2 = ply orientations (degrees) of the laminate stacking sequence (see 6.1.2),

m_1, m_2 = number of plies at each particular orientation θ_1, θ_2, . . . (not used for a single ply) (see 6.1.3),

b_1, b_2 = material type and form, or both, (if required) at each particular orientation θ_1, θ_2, . . . (see 6.1.5),

n = number of repetitions of the bracketed group of plies (see 6.1.4),

s = indication of geometric symmetry (see 6.1.6), and

b = indicator of material type and form, or both, (if required) for an abbreviated group of plies.

[1] This practice is under the jurisdiction of ASTM Committee D-30 on Composite Materials and is the direct responsibility of Subcommittee D30.01 on Editorial/Reference Standards.

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[2] *Annual Book of ASTM Standards*, Vol 15.03.

[3] Available from DOD Single Stock Point, 700 Robbins Ave., Building 4D, Philadelphia, PA 19111-5094, http://www.dodssp.daps.mil/

[4] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

[5] *NASA/DOD Advanced Composites Design Guide*, Vol 4, Section 4.0.5, Air Force Wright Aeronautical Laboratories, Day, OH, prepared by Rockwell International Corp., 1983 (distribution limited).

[6] Masters, J. E., and Portanova, M. A., *Standard Test Methods for Textile Composites*, NASA CR-4751, NASA Langley Research Center, 1996.

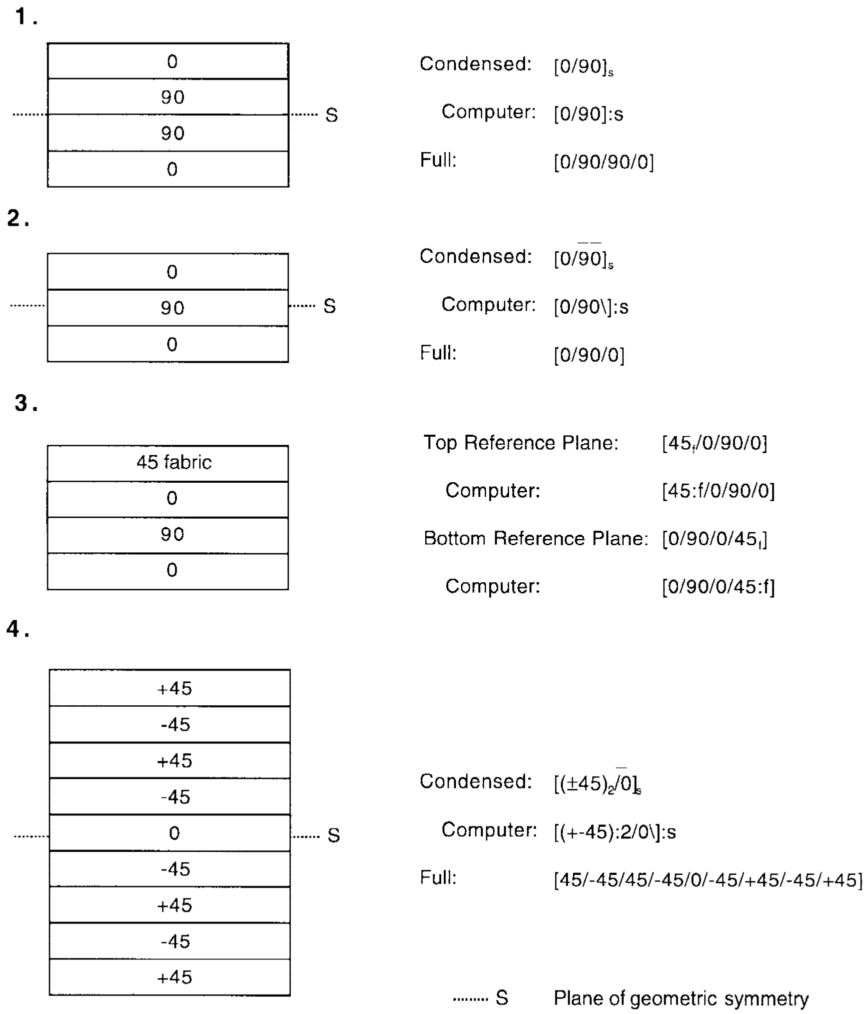

FIG. 1 Examples of Laminate Orientation Code

All subscripts are lowercase with the exception of *'T'* for total (see 6.1.6).

6.1.1 Laminae are listed in order from the reference plane to the opposite side of the laminate. Square brackets are used to indicate the beginning and the end of the code.

6.1.2 The orientation of each lamina with respect to the reference direction is indicated by the angle between the principal fiber direction of that lamina and the reference direction. When indicating the lay-up of a weave, the angle is measured between the warp direction and the reference direction. Positive angles are measured counter-clockwise from the reference direction when looking toward the lay-up surface (right-hand rule). A consistent range of angles is used with all angles in the range $90 \geq \theta > -90$. Orientations of successive laminae with different values are separated by a virgule (/). Pairs of plies of equal and opposite angle may be indicated by plus-minus (±) and minus-plus (∓) symbols, where the top of the symbol indicates the direction of the first ply. For example, [+45/–45/–45/+45] is the same as [± 45/∓45].

6.1.3 Ply symbols for two or more adjacent laminae with the same orientation and material system can be condensed by writing the common angle (and material form, if necessary) followed by a subscript equal to the number of identical plies. See Example 4 in Fig. 1.

6.1.4 When a laminate contains repeated and adjacent subsets of laminae, the code can be shortened by enclosing each subset in parentheses with the closing parentheses followed by *n*, *s*, and *b* subscripts that apply to the entire subset, as appropriate. As many subsets as necessary to describe the laminate may be used within the square brackets. The entire set of laminae within the square brackets may be repeated as indicated by an optional final set of subscripts outside the closing bracket. For example:

Full: [0/60/-60/0/90/0/90/0/60/-60/0/90/0/90/90/0/90/0/-60/60/0/90/0/90/0/-60/60/0]

Condensed: $[0/\pm 60)/(0/90)_2]_{2s}$

6.1.5 The convention used for indicating materials with the *b* subscript is no subscript for a tape ply and a subscript of "f" for a weave (fabric). If the entire lay-up contains one type of lamina, the appropriate subscript (for example, "f") may follow the closing square bracket. The laminate code for an interply hybrid has the different materials contained in the laminate indicated by unique subscripts on the laminae. The relation between subscript and material type must be identified in the notes at the end of the code.

6.1.6 All symmetry considered in this document is about the midplane of the laminate. A subscript of "s" is used if the first half of the lay-up is indicated and the second half is symmetric with the first. When a symmetric lay-up with an odd number of laminae is shown, the layer bisected by the midplane is indicated by overlining the angle of that lamina. The strict interpretation of this notation is that half of that lamina lies within each of the two parts of the symmetric laminate. Where the subscript ′*s*' is not used, a subscript ′*T*' (for total) may be used to indicate that the entire lay-up is indicated.

6.1.7 Additional notes to describe orientation of ply faces, identification of materials used in the laminate, and so on, may appear at the end of the orientation code.

6.2 Since many computer programs do not permit the use of subscripts and superscripts, the following modifications are recommended based on Guide E 1309. This form is included in Fig. 1, except for laminate orientation codes that require no modification.

6.2.1 Subscript information is preceded by a colon (:), for example, [90/0:2/45]:s.

6.2.2 A bar over a ply (designating a nonrepeated ply in a symmetric laminate) is indicated by a backslash (\) after the ply, for example, [0/45/90\]:s.

6.2.3 Plus-minus (±) and minus-plus (∓) symbols are replaced by "+–" or "–+."

6.3 This lay-up code may also be used for filament-wound materials in which the 0° direction is usually the winding axis of symmetry, and the reference plane is usually the tool surface.

7. Braiding Orientation Codes

7.1 The following information describes the two-dimensional braiding orientation code.

7.1.1 Fiber direction, yarn size, and number of layers are indicated using the following braiding orientation code:

$$[0_{m_1}/\pm\,\theta_{m_2}\ldots]_n \; N \text{ notes} \tag{2}$$

where:

θ = braid angle,
m_1 = number of fibers in the axial yarn bundles (k used for thousands),
m_2 = number of fibers in the braided yarn bundles (k used for thousands),
n = number of braided layers in a laminate, and
N = volume percentage of axial yarns in the preform.

7.1.2 Volume percentage of axial yarns in the preform provides an indication of the relative modulus of a preform in the principal axial directions. The volume percentage is calculated from information about the braider yarns and the axial yarn. In a two-dimensional triaxial braid, there are two braider yarns and one axial yarn in a unit. Choosing a unit volume, the total (combined) length of the two braider yarns is calculated from the axial yarn length (l_A) and the braid angle (BA) as follows:

$$l_B = 2l_A/\cos(BA) \tag{3}$$

The total braider yarn content (assuming unit thickness) is the total braider yarn length times the cross-sectional area of the braider yarn (A_B). The total axial yarn content is the axial yarn length (l) times the cross-sectional area of the axial yarn (A_A). The total yarn content is the sum of these two computations. The percentage of axial yarn in the preform is then the total axial yarn content divided by the total yarn content (the sum of the total axial and total braider yarn contents) as follows:

$$N = A_A/\{[2\,A_B/\cos\ (BA)] + A_A\} \tag{4}$$

If the same fiber (that is, AS4, IM6, and so forth) is used in the axial and braider yarns, the cross-sectional areas are proportional to the number of fibers in the yarns. Given this simplification, the equation to compute the axial yarn contents is as follows:

$$N = n_A/\{[2\,n_B/\cos\ (BA)] + n_A\} \tag{5}$$

Note, this computation ignores yarn crimp and jamming of the yarn bundles.

7.1.3 Examples in Table 1 illustrate the use of the braiding orientation code.

8. Keywords

8.1 composite materials; continuous-fiber-reinforced composite materials; orientation codes

TABLE 1 Examples of Braiding Orientation Code

Braid Code	Axial Yarn Size, k	Braid Angle, °	Braided Yarn Size, k	Number of Layers	Axial Yarn Content, %
$[0_{30k}/\pm70_{6k}]_3$ 63 %	30	±70	6	3	63
$[0_{12k}/\pm60_{6k}]_5$ 33 %	12	±60	6	5	33