CAx-IF Recommended Practices

for

Composite Materials

Version 4.2, August 17, 2021

Status: Final

Contacts:

CAx-IF	
Jochen Boy PROSTEP AG jochen.boy@prostep.com	**Phil Rosché** ACCR, LLC. rosche@scra.org
Technical	
Keith Hunten Lockheed Martin Aeronautics (retired) KAHunten@gmail.com	**Robert Lipman** NIST robert.lipman@nist.gov

Preface

This document is to be a supplement to the existing AP 242 ed2 Recommended Practices document and is an update to Revision 3.6 Composite Material Recommended Practices document to reflect changes to ply orientation specification.

Please direct technical questions relating to this document to:

Keith A. Hunten

Tel: +1 (817) 637-5166

Email: KAHunten@gmail.com

Document History

Revision	Section / Figure	Change
3.4	Section 3.1.2.1	Update ply orientation specification
3.4	Figures 4, 5, 7, 8, 10, 11, 14, 15, 16, 17, 21, 22	Update figures to reflect new ply orientation specification instantiations
4.0	Section 3.1.2.3	Add descriptions of nominal vs manufacturing edge of ply
4.0	Section 3.1.2.2	Add description of multiple Rosettes
4.0	Annex A	Add Notes to define abbreviations in instantiation diagrams
4.0	Front matter	Restrict scope of this document to AP242 ed2
4.0	Figure 20	Corrected diagram to properly represent reinforcement orientation basis
4.0	Figure 8	Replaced figure with correct figure
4.1	Section 3.1.1	Added description of “associated shape”
4.1	Figure 4	Added entities used to represent “associated shape”
4.1	Sections 3.1.1.1 through 3.1.1.5	Added a NOTE referring to Section 3.1.1 for a description of “associated shape”
4.1	Section 3.1.1.5	Changed references to percentage_ply_definition to percentage_ply
4.1	Figure 11	Changed references to percentage_ply_definition to percentage_ply
4.1	Section 3.1.2.2	Added a clarification that there should be one {property_definition.name = 'basis'} for each rosette
4.2	Section 3.1.2.2	Changed the description of curve_11 angle offset to match the 3ds approach agreed to by the LOTAR Composites working group

Contents

Table of Contents

Figures

Tables

1 Introduction

This Recommended Practices document has been prepared as a usage guide for industry. This document assumes that the reader has at least a rudimentary knowledge of both 10303 STEP and its associated AP242 ed2 (10303-242 ed2) application domains. The figures in this document are intended to provide a navigational view of portions of the AP with boxes representing entities, lines being relationships, and arrow heads indicating the pointer direction. This document is to be a supplement to the existing AP 203ed2 Recommended Practices document and is an excerpt and superset from the existing AP 209ed2 Recommended Practices document.

This document will provide pre- and post-processor recommendations where attributes from the conceptual STEP data models may not actually have values in the AP242 ed2 application domains. The terms pre-processor and post-processor refer to the applications that write and read the application data respectively. In these recommendations, the term 'no standard mapping' means there is no mapping defined in the AP's ARM-to-AIM mapping table for the data.

2 Document Identification

For validation purposes, STEP processors shall state which Recommended Practice document and version have been used in the creation of the STEP file. This will not only indicate what information a consumer can expect to find in the file, but even more important where to find it in the file.

This shall be done by adding a pre-defined ID string to the `description` attribute of the `file_description` entity in the STEP file header, which is a list of strings. The ID string consists of four values delimitated by a triple dash ('---'). The values are:

Document Type---Document Name---Document Version---Publication Date

The string corresponding to this version of this document is:

CAx-IF Rec.Pracs.---Composite Materials---4.0---2020-10-08

It will appear in a STEP file as follows:

```
FILE_DESCRIPTION(('...','CAx-IF Rec.Pracs.---Composite Materials---4.0---2020-
10-08',),'2;1');
```

3 Using AP242 ed2 to represent Composite Material Shape and Structure

This section describes how AP242 ed2 is intended to be used to represent structures made of composite materials. This section will establish examples and limits on some of the data constructs that are not constrained in the Application Interpreted Model (AIM) of the Application Protocols (AP).

3.1 Composite Part and Constituent Representations

A composite part is made of constituents that are laminated in layers to create the part. AP 242 ed2 provides specialized product definitions to represent the structural makeup and properties of composite parts in SUBTYPEs of Laminate_tables. The ARM EXPRESS-G for Laminate_table is shown in Figure 1, and the MIM EXPRESS-G in Figure 2.

NOTE: The names of the SUBTYPEs in the MIM of the original AP209 ed1 were different. These names were changed in the interests of clarity for implementers. Table 1 summarizes these changes.

New SUBTYPE Name	Old SUBTYPE Name
ply_laminate_table	ply_laminate_definition
composite_assembly_table	composite_assembly_definition
thickness_laminate_table	thickness_laminate_definition
percentage_laminate_table	percentage_laminte_definition
UNCHANGED	smeared_laminate_definition

Table 1: Changes in SUBTYPEs from AP209 ed1 to Current STEP Composites

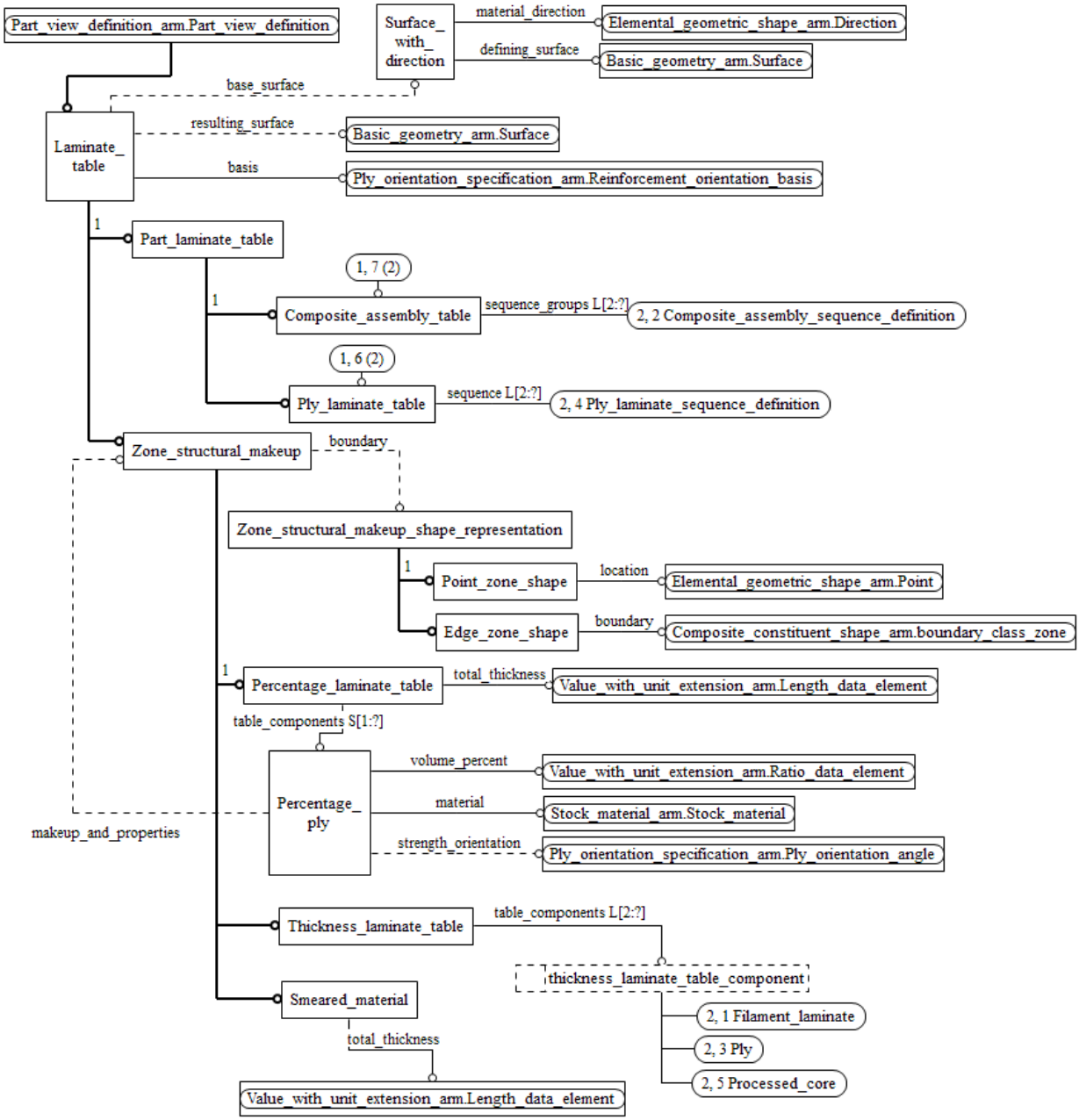


Figure 1: Composite Laminate Table ARM Subtypes

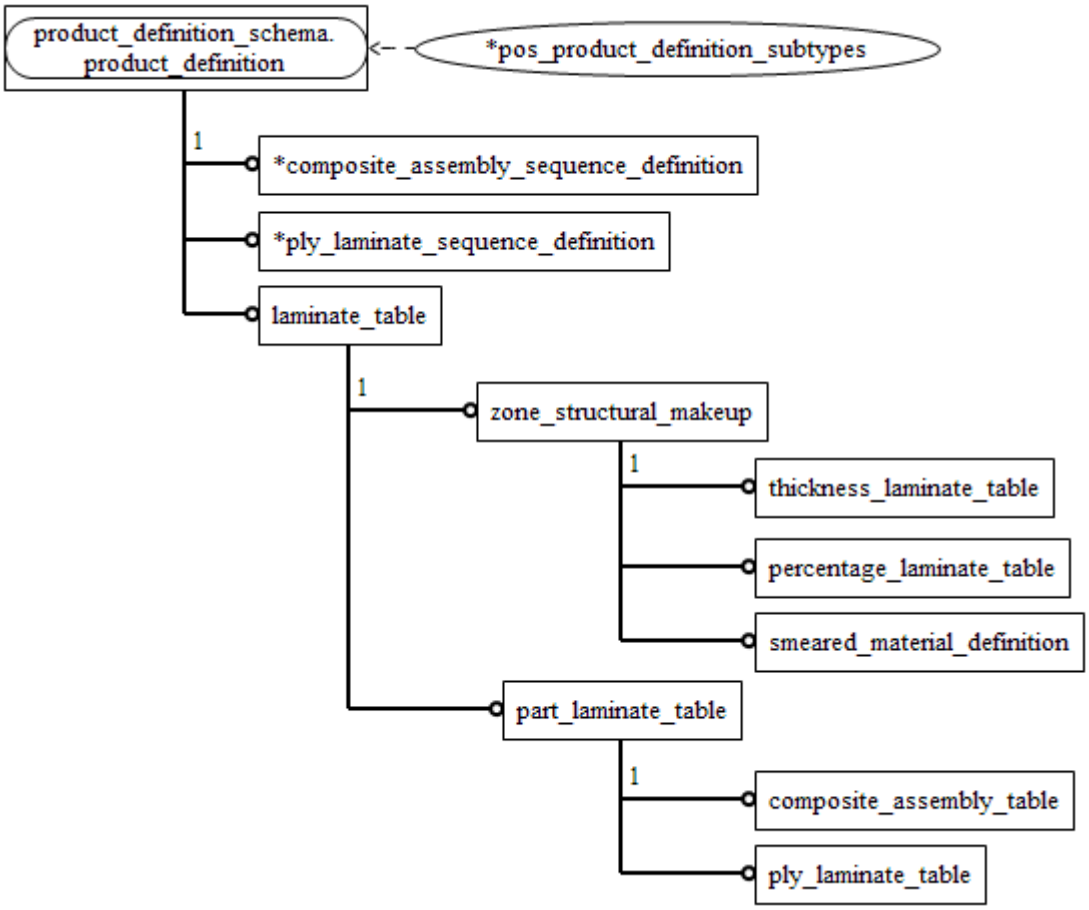


Figure 2: Composite Laminate Table MIM Subtypes

Ply, `processed_core`, and `filament_laminate` are the basic constituents in composite parts. A ply laminate is a composite part is composed of layers or sequences of plies. A `composite_assembly` is also constructed in layers, except that a composite assembly may have sequences of constituents other than plies, such as processed core, and may contain ply laminates and other composite assemblies as constituents. The ARM diagram illustrating the composite constituents is shown in Figure 3.

Note that there are no specific MIM entities for the composite constituents. The instantiation rules are set in the mapping table of ISO 10303-1770 Part and zone laminate tables. Specific implementation examples are illustrated in 3.1.2.

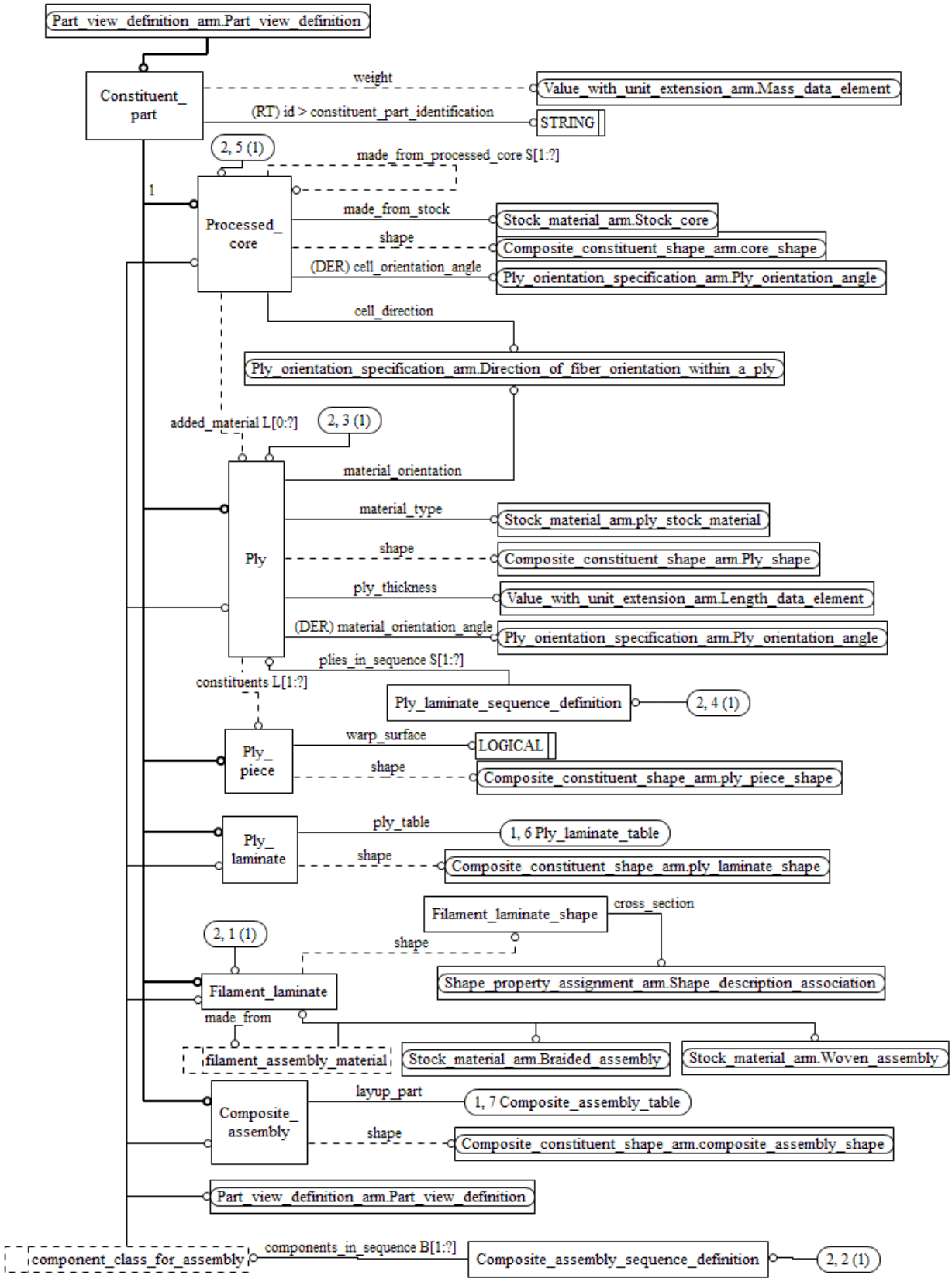


Figure 3: ARM Composite Constituents

3.1.1 Composite Part Structural Representation

The structural makeup of a composite part is described by a laminate table. The laminate table exists as one of its two subtypes: part laminate table and zone structural makeup. The part laminate table describes allocation of the physical constituents for the overall laminate, while the zone structural makeup is used to describe the physical constituents for a particular zone, area, or point on the part. The part laminate table and zone structural makeup in turn exist as one of their respective subtypes. The part laminate table is called the ply laminate table for a ply laminate part, and the composite assembly table for a composite assembly part. The zone structural makeup may be a thickness laminate table or percentage laminate table that provides allocation of the composite constituents by thickness or percentage, respectively. A smeared material definition is a special case of zone structural makeup representation, where all the composite constituents across the thickness are lumped together.

Associated with each laminate table is a `shape_representation` for the base surface of the composite part, which includes in its set of items a surface and a direction that specifies the material side. The surface and direction geometric `representation_items` shall be the first and second `representation_items` respectively in the items of this `shape_representation`. The name attribute of the surface `representation_item` is set to `'base_surface'`. A second `shape_representation` may be used to represent the opposing surface that results from the build-up of material on the base surface, with the name attribute of the surface `representation_item` is set to `'resulting_surface'`. Both surfaces are represented as shape aspects for the laminate table (Figure 4).

Normally the shape of a composite part is represented by the sum of the shapes of the composite constituents of the laminate table. Optionally associated with a laminate table (and therefore all of its subtypes) is zero, one or many “associated shape” for the cases where another shape representation is required to add information, typically referred to as “Edge of Part” (EOP). The representation context of these associated shape(s) must be identical or related to the representation context of the laminate table. The type of “associated shape” is defined by the `shape_aspect.name` attribute, where typical values may be such as “nominal shape” or “manufacturing shape”, while the attribute `shape_aspect.description` provides further information.

NOTE 1: Figure 4 applies to ply laminate table, composite assembly table, thickness laminate table, percentage laminate table, and smeared material as follows: Ply laminate table and composite assembly table are subtypes of part laminate table, which is in turn a subtype of laminate table. Hence, ply laminate table and composite assembly table inherit all of the attributes of laminate table and part laminate table. Likewise, thickness laminate table, percentage laminate table, and smeared material are subtypes of zone structural makeup, which is in turn a subtype of laminate table. Hence, thickness laminate table, percentage laminate table, and smeared material inherit all of the attributes of laminate table and zone structural makeup. Finally, the “associated shape” in Figure 4 applies to all the subtypes of laminate table. The mapping for these entities are as follows:

laminate table	`product_definition`
part laminate table	`product_definition`
zone structural makeup	`product_definition`
ply laminate table	`ply_laminate_table <= product_definition`
composite assembly table	`composite_assembly_table <= product_definition`
thickness laminate table	`thickness_laminate_table <= product_definition`
percentage laminate table	`percentage_laminate_table <= product_definition`
smeared material	`smeared_material_definition <= product_definition`

Table 2: Laminate Table Mappings

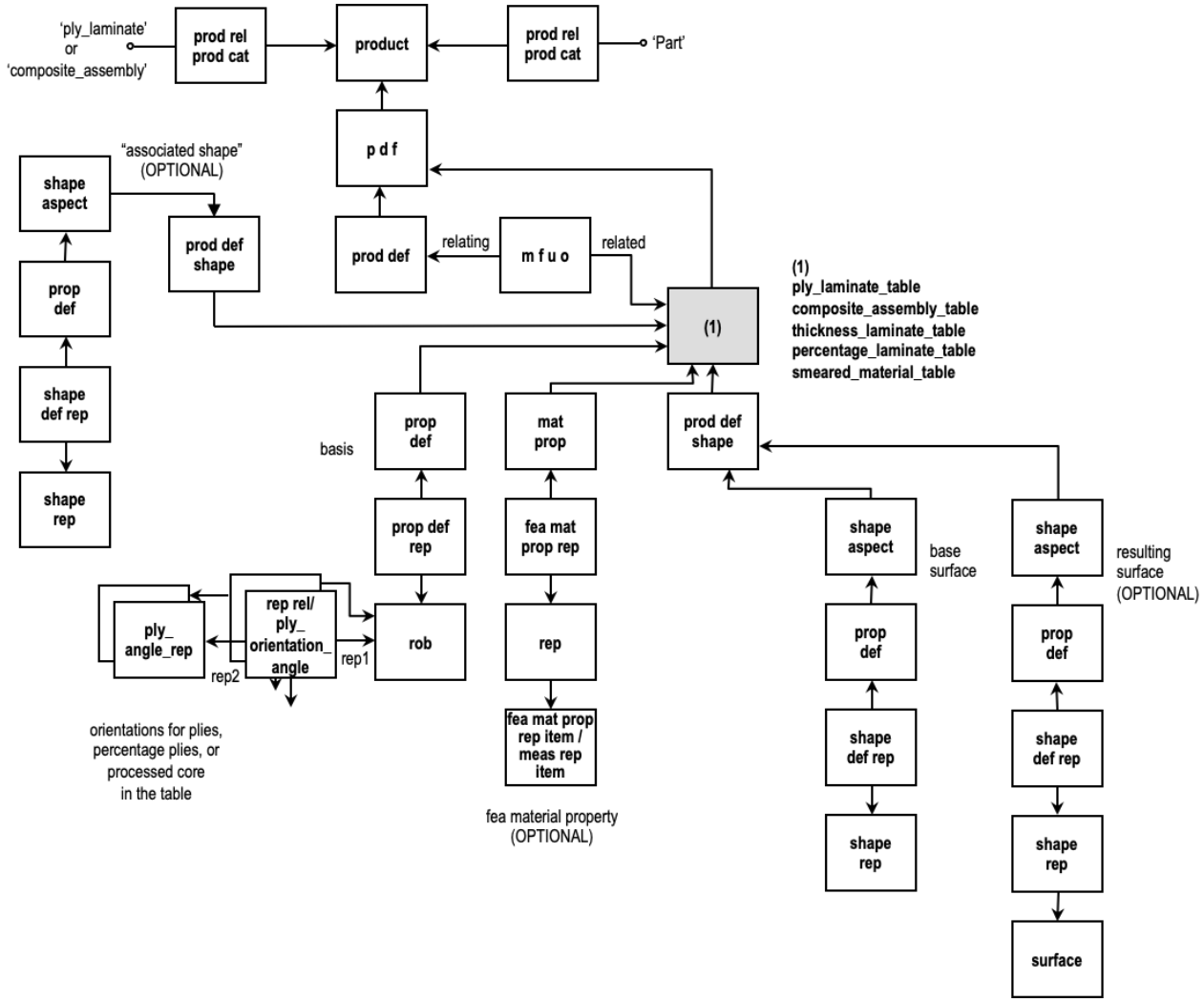


Figure 4: Laminate Table

NOTE 2: Figure 4 also shows a reference to a `product_related_product_category` with a string of 'Part'. This is quite important as it documents the fact that the `laminate_table` Part is *ALSO the Part* that is a member of the product structure.

A laminate table is also characterized by one or many reinforcement orientation bases (rosettes). See 3.1.2.2 for a complete discussion on laminate and ply orientation specification.

NOTE 3: See Annex A for the abbreviations used in Figure 4.

The material properties to be used in the finite element analysis of a composite part may be specified by associating the overall properties to the laminate table. To this end, the `fea_material_property_representation` entity is used to relate the material property representation to the `product_definition` for the laminate table.

3.1.1.1 Ply Laminate Table

The ply laminate table that describes the sequencing of ply layers for a ply laminate is represented by a `ply_laminate_table` in AP242 ed2. The `product_definition` for a ply laminate part or constituent is related to the ply laminate table by a `make_from_usage_option`. Each layer in the laminate is represented by a `ply_laminate_sequence_definition`. The first `ply_laminate_sequence_definition` in the table is related to the `ply_laminate_table` by a `next_assembly_usage_occurrence` entity. The `ply_laminate_table` is the `relating_product_definition`, and the `ply_laminate_sequence_definition` is the `related_product_definition` in this relationship. Subsequent layers in the ply laminate are likewise related to the preceding layer through `next_assembly_usage_occurrences`, thus forming a chain of `ply_laminate_sequence_definitions` (Figure 5). The `ply_laminate_table` and the associated `ply_laminate_sequence_definitions` all point to the `product_definition_formation` for the ply laminate part.

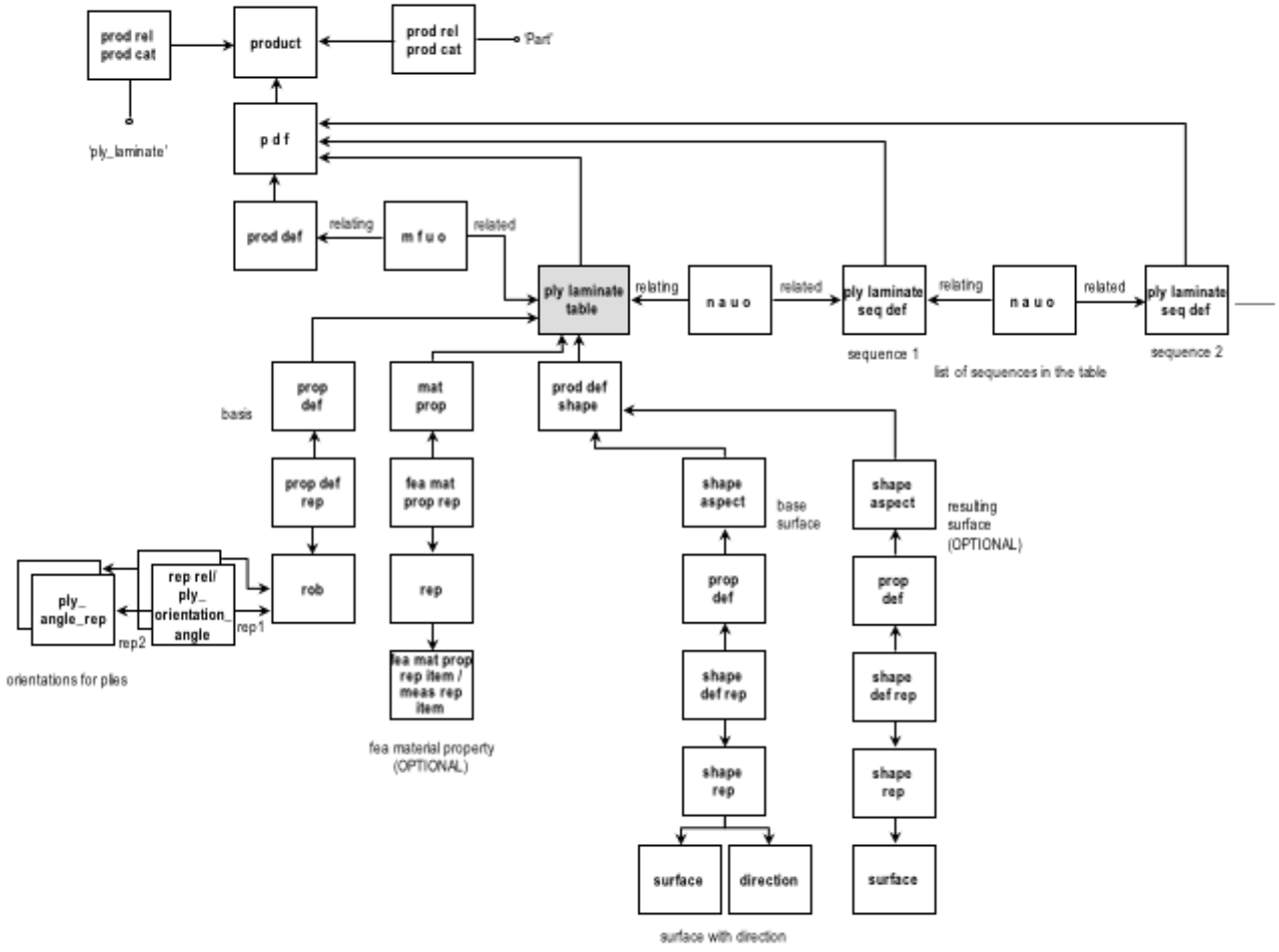


Figure 5: Ply Laminate Table

NOTE 1: See Annex A for the abbreviations used in Figure 5.

NOTE 2: See Figure 4 and Note 1 in 3.1.1 for details of associated an “associated shape”.

A layer in a ply laminate may contain one or more plies. Each of the ply `product_definitions` in a sequence are related to the `ply_laminate_sequence_definition` by a `next_assembly_usage_occurrence` entity, forming a tree of ply `product_definitions` (Figure 6).

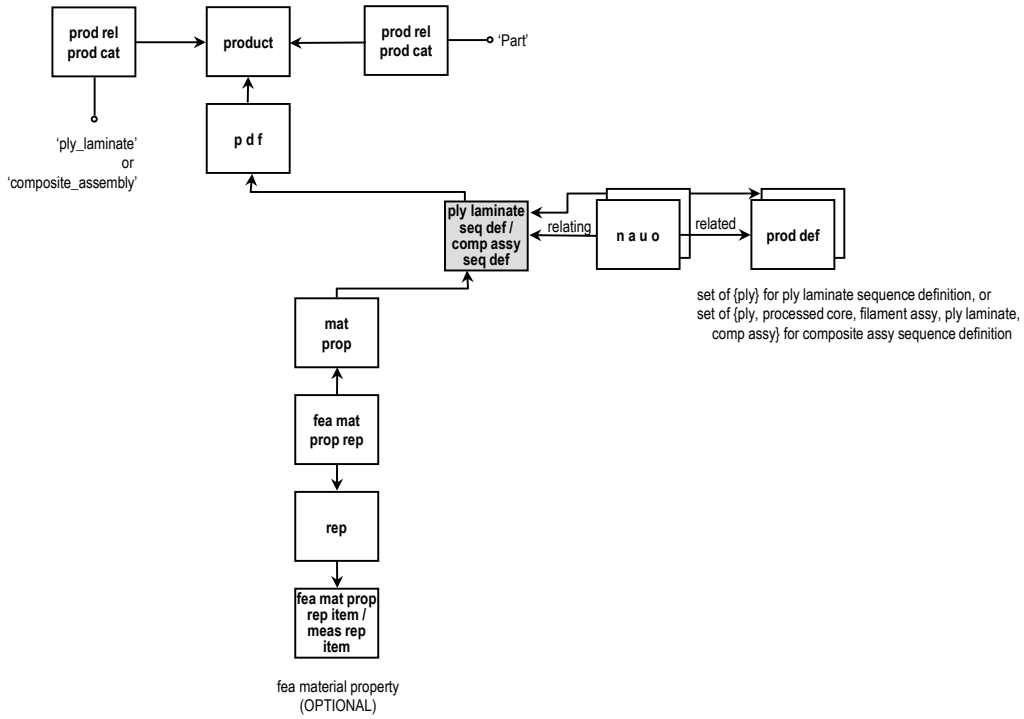


Figure 6: Part Laminate Table Sequence Definitions

NOTE 2: See Annex A for the abbreviations used in Figure 6.

NOTE 3: See Figure 4 and Note 1 in 3.1.1 for details of associated an “associated shape”.

The material properties to be used in the finite element analysis of a ply laminate part may be specified by associating the overall properties to the laminate table as discussed above (see 3.1.1.1), or by associating the properties to each sequence in the `ply_laminate_table`. The `fea_material_property_representation` entity is used to relate the material property representation to a `ply_laminate_sequence_definition`.

3.1.1.2 Composite Assembly Table

A composite assembly is similar in structure to a ply laminate, except that a composite assembly may have sequences of constituents other than plies, such as processed core, and may include other assemblies. A composite assembly structure is thus represented by a chain of `composite_assembly_sequence_definitions` headed by a `composite_assembly_table` (Figure 6). The `composite_assembly_table` and the associated `composite_assembly_sequence_definitions` all point to the `product_definition_formation` for the composite assembly part.

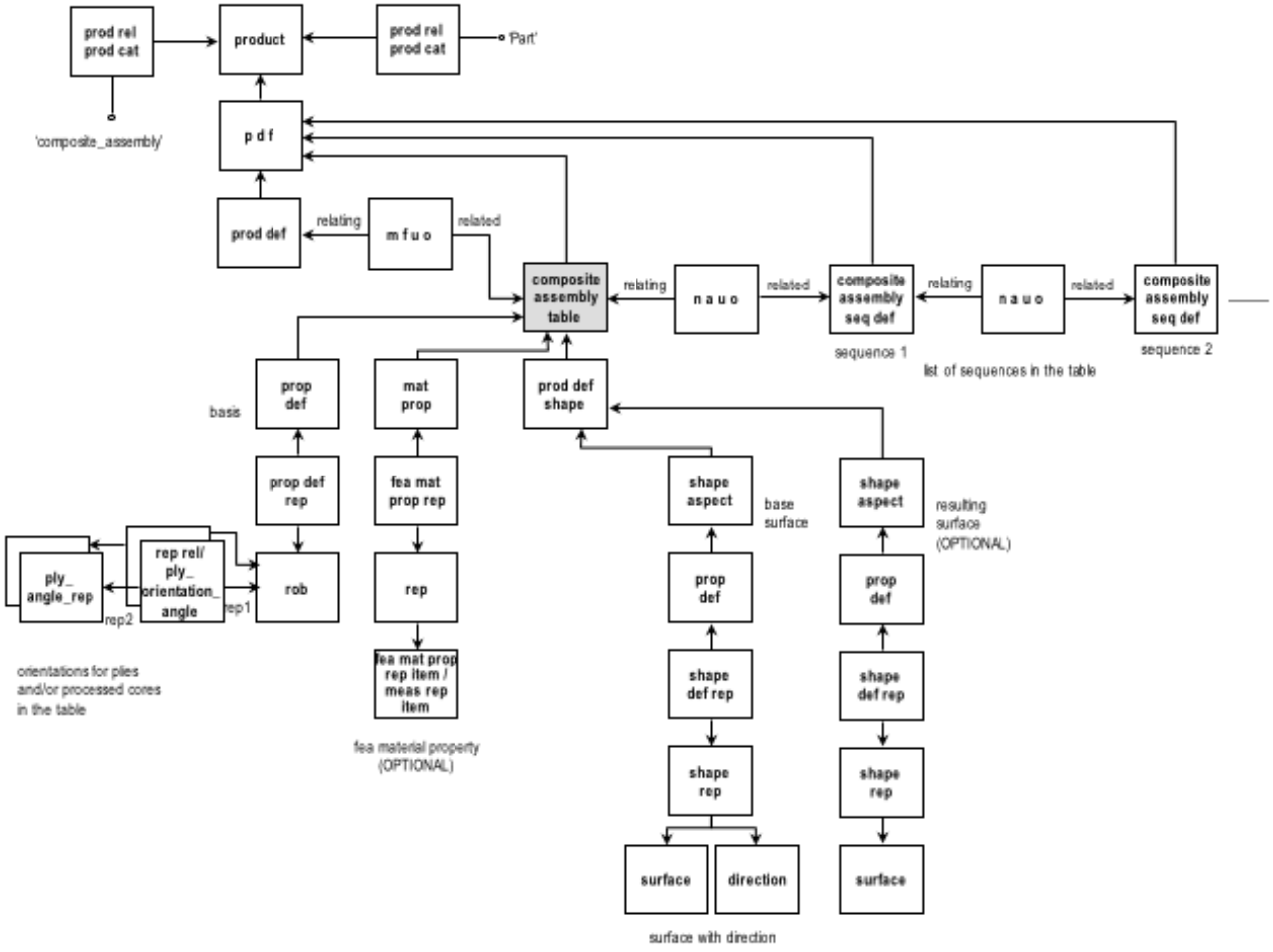


Figure 7: Composite Assembly Table

NOTE 1: See Annex A for the abbreviations used in Figure 7.

NOTE 2: See Figure 4 and Note 1 in 3.1.1 for details of associated an “associated shape”.

Like the `ply_laminate_sequence_definition`, the `composite_assembly_sequence_definition` is linked to its composite constituent `product_definitions` through branches of `next_assembly_usage_occurrences` (Figure 6).

The material properties to be used in the finite element analysis of a composite assembly part may be specified by associating the overall properties to the laminate table as discussed above (see 3.1.1.1), or by associating the properties to each sequence in the `composite_assembly_table`.

The `fea_material_property_representation` entity is used to relate the material property representation to a `composite_assembly_sequence_definition`.

3.1.1.3 Thickness Laminate Table

A thickness laminate table, represented by a `thickness_laminate_table`, is used to specify composite constituents that make up a zone of a composite part. A `thickness_laminate_table` is structured similar to a `composite_assembly_table` as can be seen in Figure 8. Since each layer or sequence is local, the corresponding 'sequence' definition contains a single composite constituent that is either a `ply`, `processed_core`, or a `filament_laminate`. The `next_assembly_usage_occurrence.relating_product_definition` identifies the `thickness_laminate_table` and the `next_assembly_usage_occurrence.related_product_definition` identifies the first product in the sequence. Subsequent products are ordered in the same manner using `next_assembly_usage_occurrence` entities. In addition to the base surface and the optional resulting surface, the zone edge shape may be specified for a thickness laminate table using a `shape_representation`.

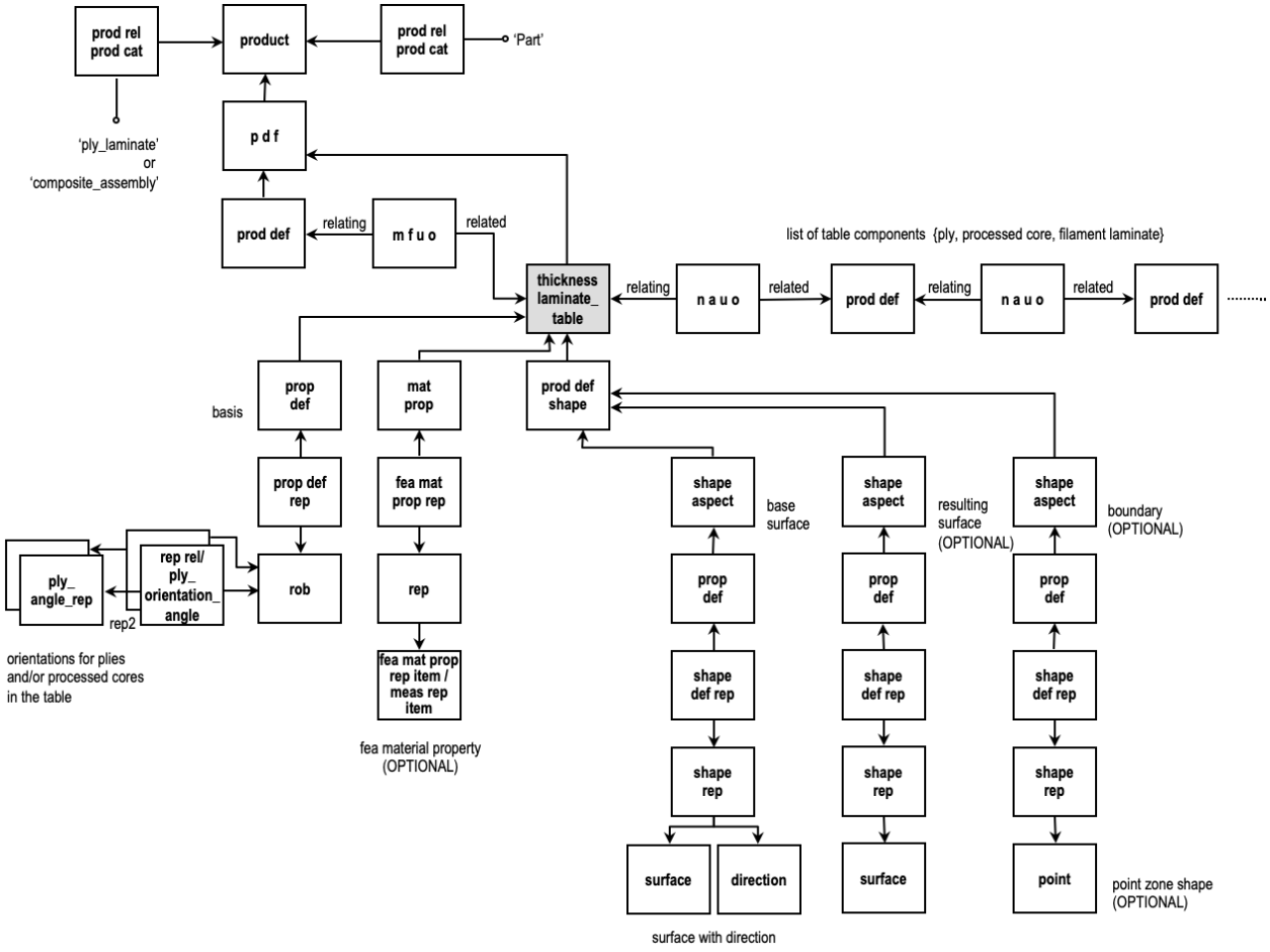


Figure 8: Thickness Laminate Table

NOTE 1: See Annex A for the abbreviations used in Figure 8.

NOTE 2: See Figure 4 and Note 1 in 3.1.1 for details of associated an "associated shape".

When multiple thickness laminate tables intersect, that is, share constituent parts, it may be necessary to distinguish the chain of `next_assembly_usage_occurrence` entities belonging to a

`thickness_laminate` table form that belonging to another. This can be accomplished by using the same description for all the `next_assembly_usage_occurrence` entities in a chain that is consistent with the description for the `thickness_laminate_table` at the top of the chain. This is illustrated in Figure 9.

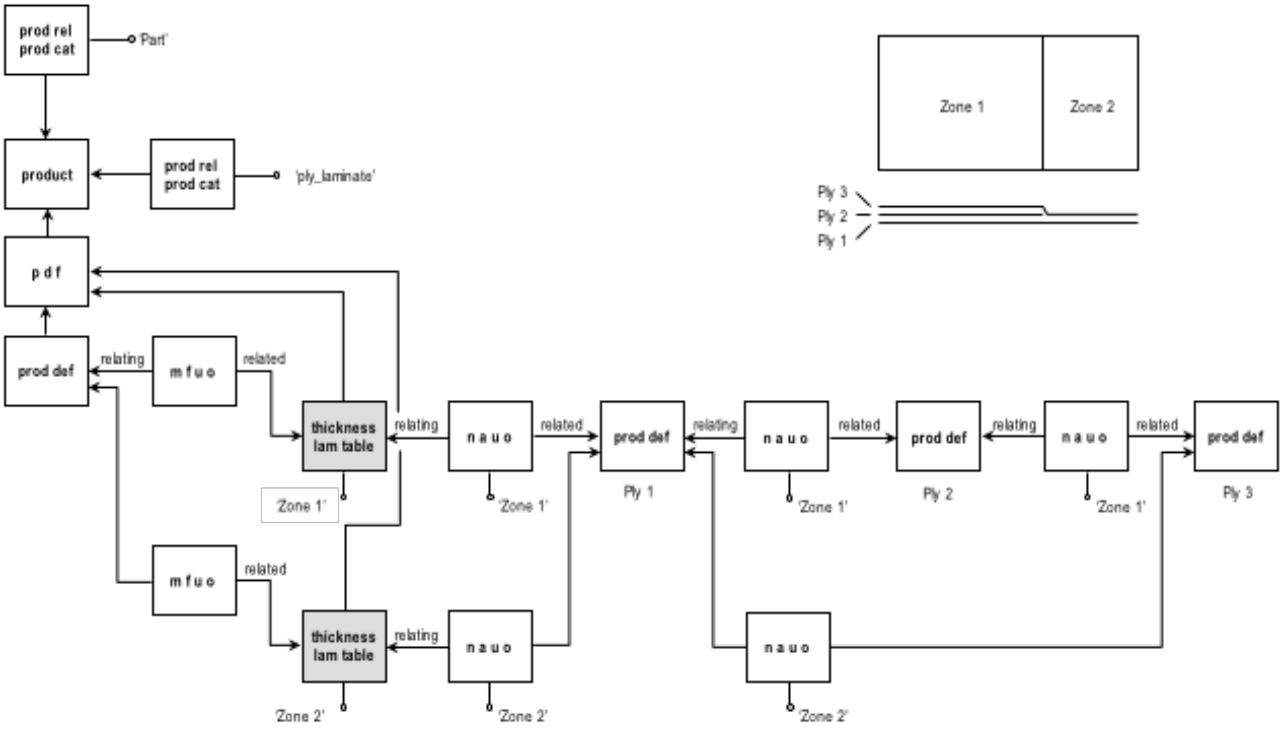


Figure 9: Multiple Zones Sharing Plies

NOTE: See Annex A for the abbreviations used in Figure 9.

3.1.1.4 Percentage Laminate Table

A percentage laminate table, represented by a `percentage_laminate_table`, is used to specify the percentages of the composite constituents at a point or area of the part. The table components are percentage plies, represented by `percentage_ply_definition` entities. Each `percentage_ply_definition` is related to the `percentage_laminate_table` by a `next_assembly_usage_occurrence` entity. A `shape_representation` may be used to represent the edge or point zone shape for the percentage laminate table. A `representation` is used to specify the total thickness for the zone. The `representation` shall have a `measure_representation_item` that has a `length_measure_with_unit` in its set of items (Figure 10).

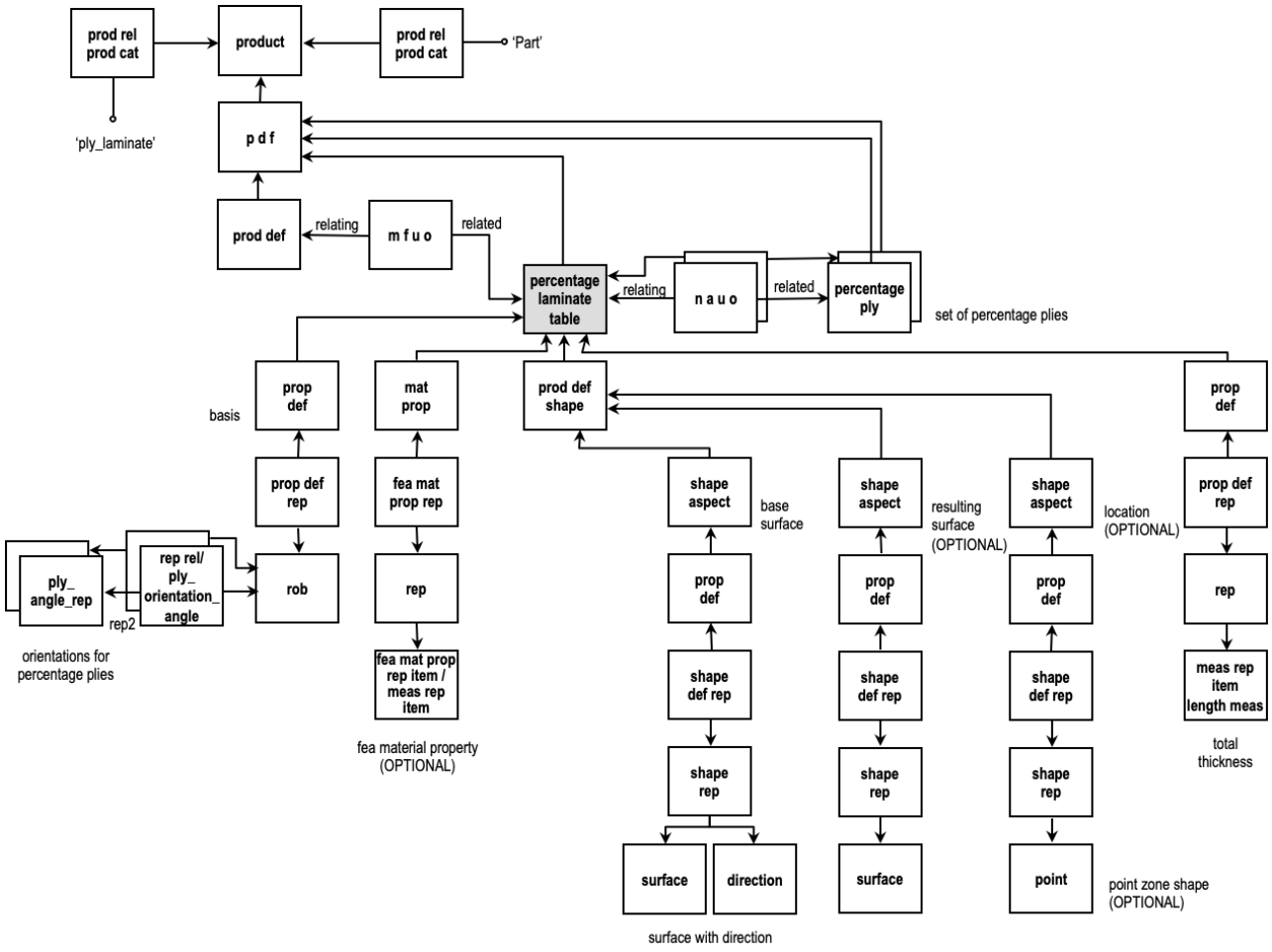


Figure 10: Percentage Laminate Table

NOTE 1: See Annex A for the abbreviations used in Figure 10.

NOTE 2: See Figure 4 and Note 1 in 3.1.1 for details of associated an “associated shape”.

3.1.1.5 Percentage Ply

A `percentage_ply` (Figure 11) is the 'composite constituent' for a percentage laminate table. A `make_from_usage_option` entity is used to relate the `percentage_-ply_definition` to its stock material `product_definition`, which is associated with a product in a `product_related_product_category` with a name of 'filament_assembly', 'discontinuous_fiber_assembly', 'stock_core', 'isotropic_material', or 'anisotropic_material'. The internal makeup of a percentage ply may in turn be specified by one of the zone structural makeup representations.

A `percentage_ply` has a representation to denote its percentage. The representation shall have a `measure_representation_item` that is a `ratio_measure` in its set of items. The volume percents of the `percentage_ply`s in the table shall add up to 100%.

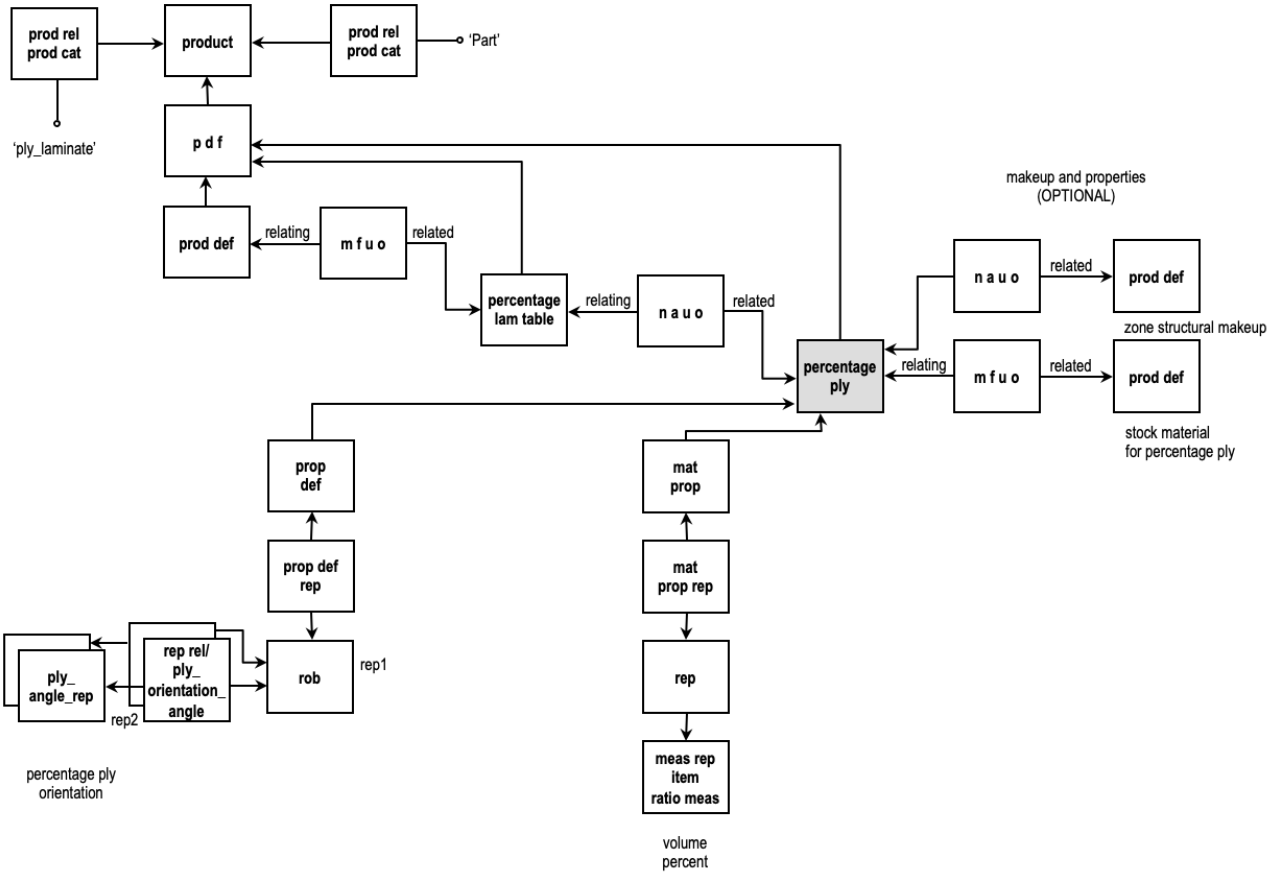


Figure 11: Percentage Ply

NOTE: See Annex A for the abbreviations used in Figure 11.

3.1.1.6 Smeared Material

A `smeared_material_definition` is an alternate definition that lumps all the composite constituents together (Figure 12). A `shape_representation` may be used to represent the zone shape for the `smeared_material_definition`. A representation is used to specify the total thickness. If the smeared material definition is used together with a percentage laminate table or a thickness laminate table, the thickness specified for the `smeared_material_definition` shall be consistent with that for the `percentage_laminate_table`, or with the sum of thicknesses of the composite constituents in the `thickness_laminate_table`.

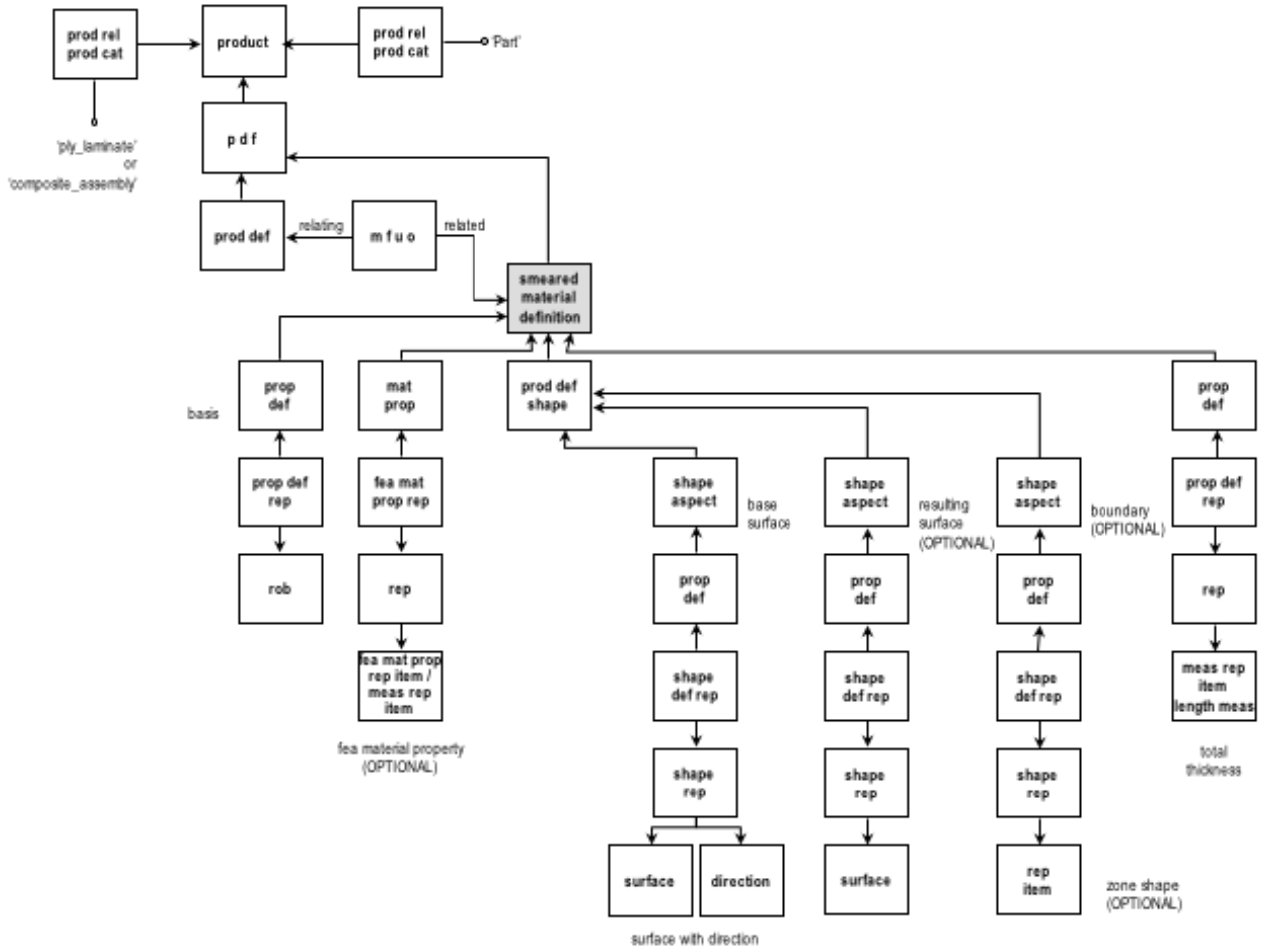


Figure 12: Smeared Material

NOTE: See Annex A for the abbreviations used in Figure 12.

3.1.1.7 Use of Point_zone_shape to represent "Core Samples"

All subtypes of ARM concept Zone_structural_makeup (Percentage_laminate_tabe, Thickness_laminate_table, and Smeared_material) may be of type Point_zone_shape or Edge_zone_shape. It is the Point_zone_shape SUBTYPE that is to be used to represent "Core Samples" – i.e. the laminate table stacking sequence at a point. See 3.1.1.3, 0, and 0 for the details of how to specify a Point_zone_shape.

3.1.2 Composite Constituent and Shape Representations

In AP 203 ed2, AP 209 ed2, and AP242 ply, processed core, and filament laminate are the basic composite constituents that are layered to form ply laminates or composite assemblies. Ply laminates and composite assemblies can also be used as composite constituents in a composite assembly.

A composite constituent exists as one of its five subtypes: ply, processed core, filament laminate, ply laminate, and composite assembly. This is indicated by associating the product for the composite constituent with a `product_related_product_category` that has the corresponding name attribute of 'ply', 'processed core', 'filament laminate', 'ply laminate', or 'composite assembly. The material for a composite constituent is specified by a `make_from_usage_option`. The constituent `product_definition` is the `relating_product_definition`, and the material `product_definition` is the `related_product_definition` in this relationship (Figure 13).

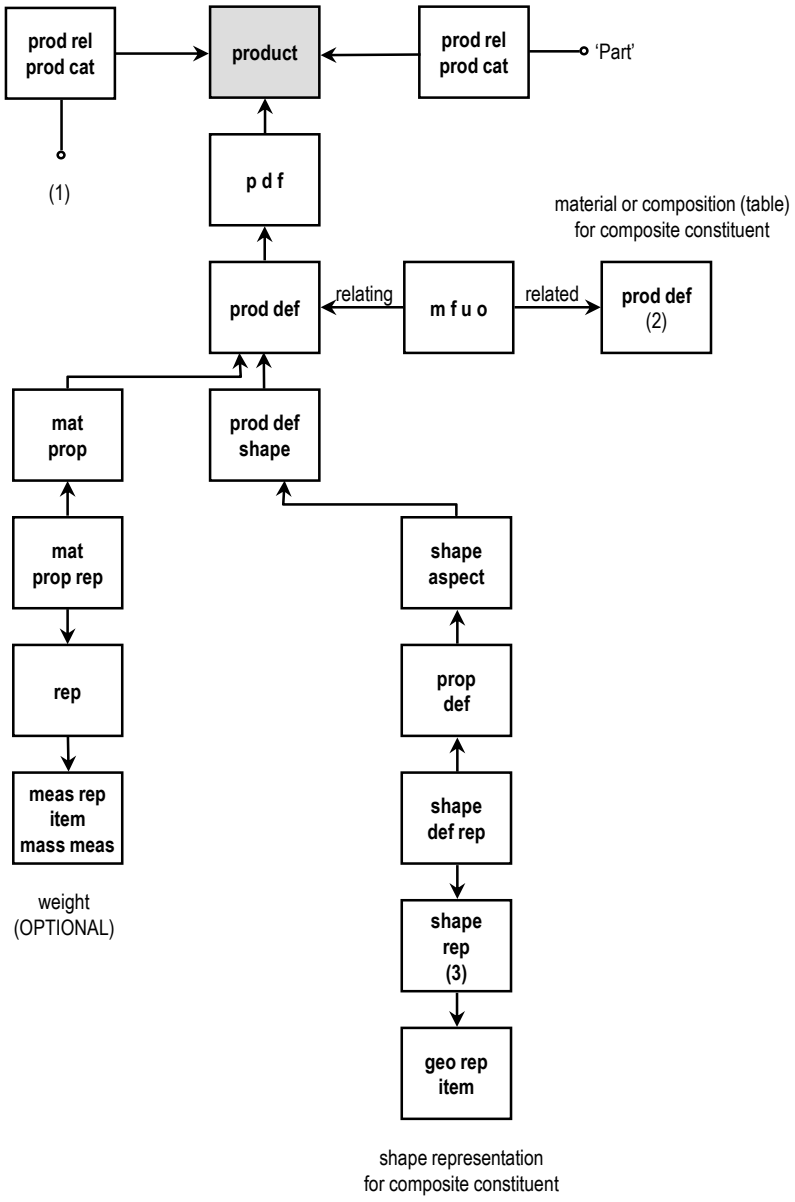


Figure 13: Composite Constituents

NOTE: See Annex A for the abbreviations used in Figure 13.

A composite constituent may have a representation to denote the weight of the constituent. A `material_property_representation` entity is used to link this representation with the `property_definition` subtype `material_property`. The representation shall have a `measure_representation_item` that is a `mass_measure_with_unit` in its set of items.

3.1.2.1 Ply

A ply product is associated with a `product_related_product_category` with a name of 'ply' (Figure 14). The ply `product_definition` is related by a `make_from_usage_option` to its stock material `product_definition`, which is associated with a product in a `product_related_product_category` with a name of 'filament_assembly', 'dicscontinuous_fiber_assembly', or 'isotropic_material'.

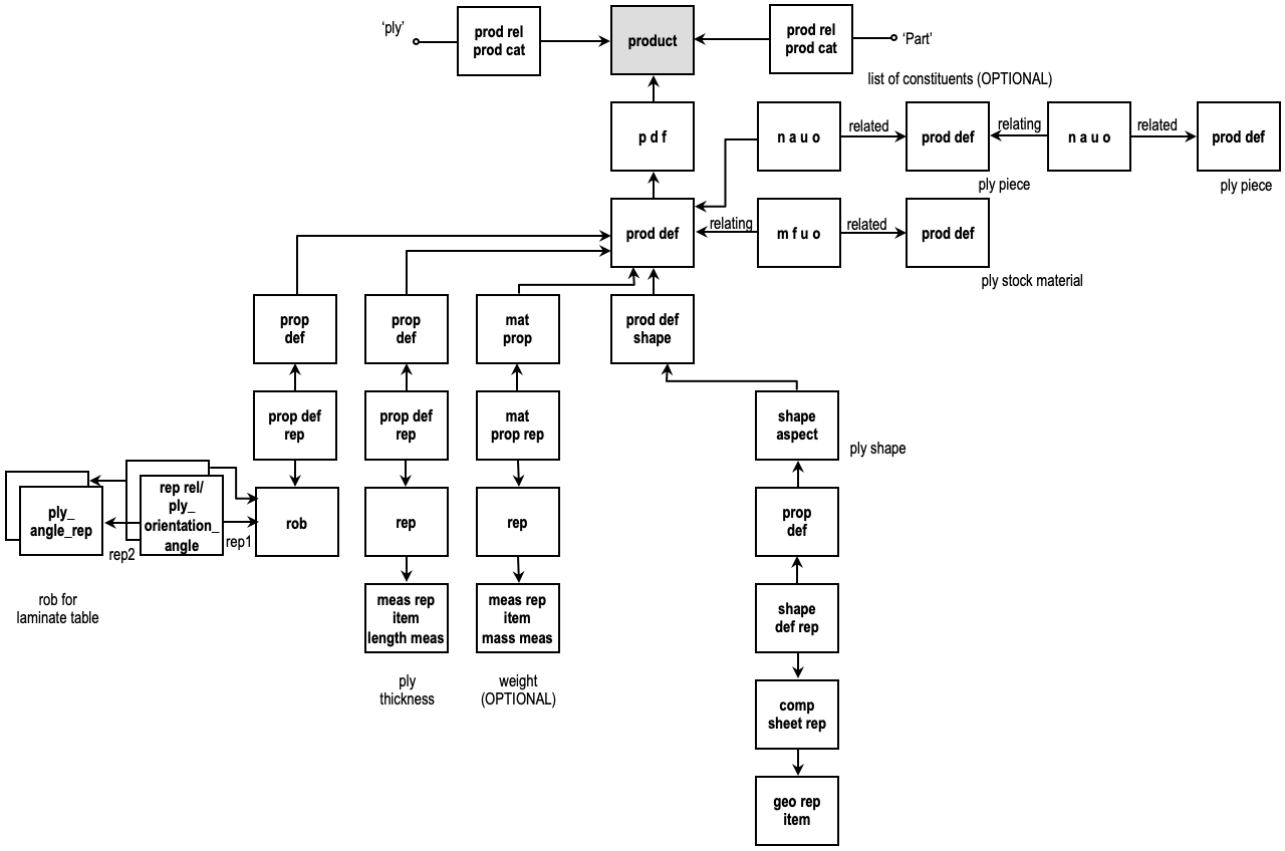


Figure 14: Ply

NOTE: See Annex A for the abbreviations used in Figure 14.

If two or more ply pieces are combined together in a single layer to make up the ply, then the list of the ply pieces shall be given by a chain of `next_assembly_usage_occurrence` entities. The first `next_assembly_usage_occurrence` in the chain shall have the `product_definition` for the ply as the `relating_product_definition`, and the `product_definition` for the first ply piece in the list as the `related_product_definition`. The second `next_assembly_usage_occurrence` in the chain shall likewise link the `product_definitions` for the first and second ply pieces in the list, and so on.

A ply has a representation to denote its thickness. The representation shall have a `measure_representation_item` that is a `length_measure_with_unit` in its set of items.

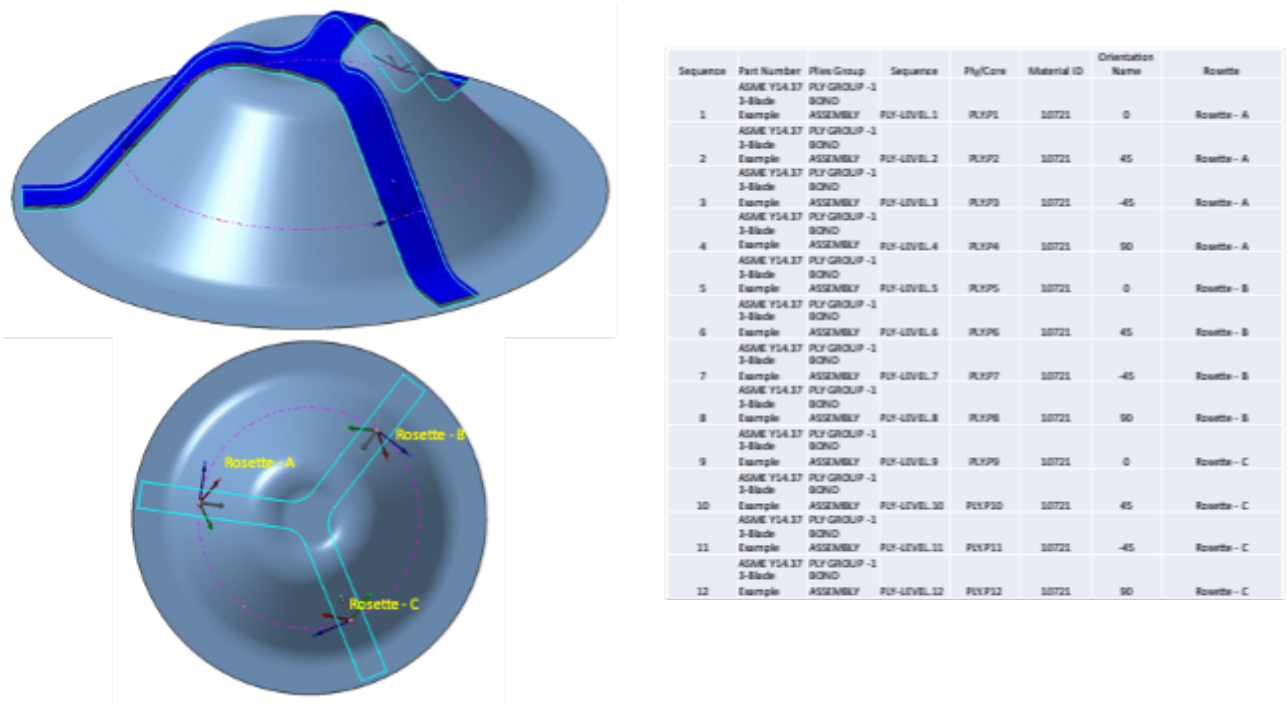
3.1.2.2 Ply Orientation

A ply has a representation to denote its fiber 11 orientation, commonly called a Rosette. The 11 direction is specified by the combination of a `reinforcement_orientation_basis` that provides the reference (or basis) direction for the ply angle, and an angle that is specified with respect to that basis direction in the plane tangent to the `base_surface` of the `laminate table`.

There may be one or many `reinforcement_orientation_basis` in a laminate table. Each ply's material orientation Rosette shall refence one of the `reinforcement_orientation_basis` of the laminate table. An example of a laminate table utilizing multiple Rosettes is shown in Figure 15.

Note that per the mapping table there should be one {property_definition.name = 'basis'} for each rosette:

property_definition.definition
{property_definition.name = 'basis'}
property_definition <-
property_definition_representation.definition
property_definition_representation
property_definition_representation.used_representation ->
representation



Sequence	Part Number	Plies Group	Sequence	Ply/Core	Material ID	Orientation Name	Rosette
1	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.1	PLYP1	10721	0	Rosette - A
2	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.2	PLYP2	10721	45	Rosette - A
3	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.3	PLYP3	10721	-45	Rosette - A
4	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.4	PLYP4	10721	90	Rosette - A
5	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.5	PLYP5	10721	0	Rosette - B
6	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.6	PLYP6	10721	45	Rosette - B
7	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.7	PLYP7	10721	-45	Rosette - B
8	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.8	PLYP8	10721	90	Rosette - B
9	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.9	PLYP9	10721	0	Rosette - C
10	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.10	PLYP10	10721	45	Rosette - C
11	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.11	PLYP11	10721	-45	Rosette - C
12	ASME Y14.37 3-Blade Example	PLY GROUP -1 BOND ASSEMBLY	PLY-LEVEL.12	PLYP12	10721	90	Rosette - C

Figure 15 Example: Multiple Rosettes for a Laminate Table

There are several ways to represent basis of the ply fiber orientation (seeFigure 16):

- A `cartesian_11` Rosette specifies that the basis 11 is the 11 direction of an `axis2_placement_3d` entity whose 33 direction is the upward (towards the topmost ply in the table) normal to the `base_surface` of the `laminate_table;`
- A `curve_11` Rosette specifies that the basis 11 direction is the tangent to the specified curve at any point along the curve where the 11 direction is to be evaluated. The ply_orientation_angle is right hand positive around the 33 direction normal to the plane, where the plane shall be tangent to the `base_surface` of the `laminate_table`. The 11 direction has an additional angle offset that is added to the ply_orientation angle with

complex instantiation of bounded_curve+composite_curve+curve+geometric_representation_item+measure_with_unit+representation_item as in #2 in the example below:

#2=(BOUNDED_CURVE()COMPOSITE_CURVE($,$)CURVE()CURVE_11()

GEOMETRIC_REPRESENTATION_ITEM()MEASURE_REPRESENTATION_ITEM()

MEASURE_WITH_UNIT($,$)REPRESENTATION_ITEM($));

- A `cylindrical_11` Rosette specifies that the basis 11 direction is a tangent to the curve at any point evaluated along a curve on the surface of the cylinder where the curve is created by the intersection of the cylinder surface with a plane through the centerline of the cylinder. The ply_orientation_angle is specified by right hand rule about the 33 direction of the outward facing normal to the plane tangent to the cylindrical `base_surface` of the `laminate_table` at the evaluated point;
- A `polar_11` Rosette specifies that the basis 11 direction is always in the radial direction from the center of the part. A Radial Rosette shall be placed in the exact center of the part, for example at the apex of a spherical cap. When the Rosette mapping takes place the direction of the 0° orientation is pointing outward in a radial direction. No guide curve is required. The ply_orientation_angle is with respect to the plane tangent to the `base_surface` of the `laminate_table` with the 33 direction parallel to the outward normal of the `base_surface`.

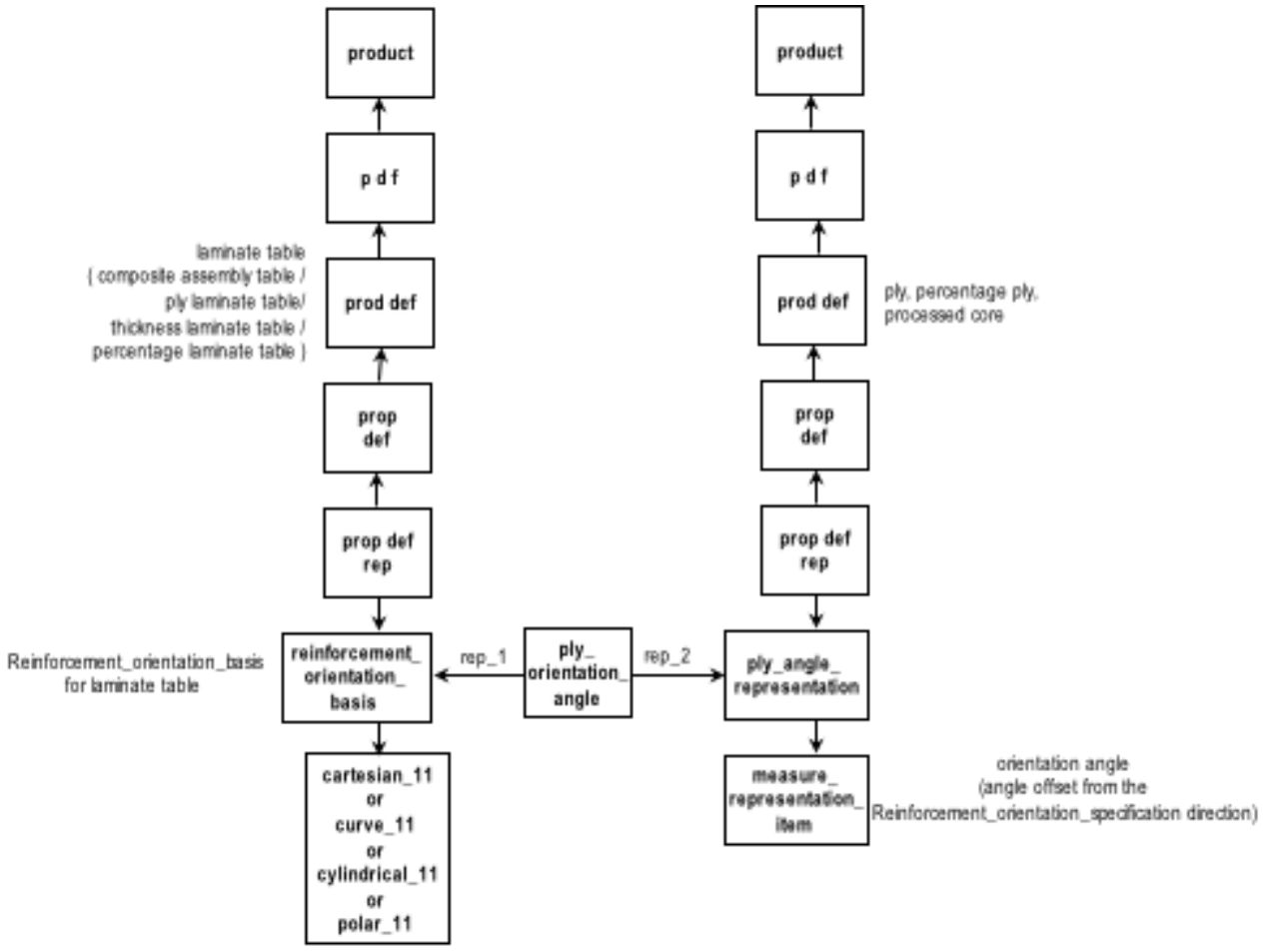


Figure 16: Ply Orientation Angle by Cartesian Placement, Curve, Cylindrical, or Polar 11 Basis Direction

NOTE 1: The full description of these ply orientation options is specified in Clause 4 of ISO 10303-1772 Ply orientation specification.

NOTE 2: See Annex A for the abbreviations used in Figure 16.

If the ply orientation is specified by a `point_array`, the major and minor directions of the `point_and_vector` entities in the point path will be associated with the axis direction of the `axis2_placement_3d`). A point array is represented in AP 203 ed2, AP 209 ed2 and AP 242 by a chain of `point_and_vector` entities, headed by a `point_array`. The `point_array` and `point_and_vector` are both subtypes of `shape_representation`. A `point_and_vector` represents a point and the associated vector pairs on a point path. The first `representation_item` in the `items` of a `point_and_vector` shall be a `point` entity, the second a `direction` entity representing the major direction, and the third a `direction` entity representing the minor direction) (see Figure 17: Ply Orientation by Point Array).

NOTE 3: The ply 11 and 22 directions are known only at the points of the `point_array`. If the ply orientations need to be known in-between them a suitable interpolation scheme, such as spline surfaces, should be used.

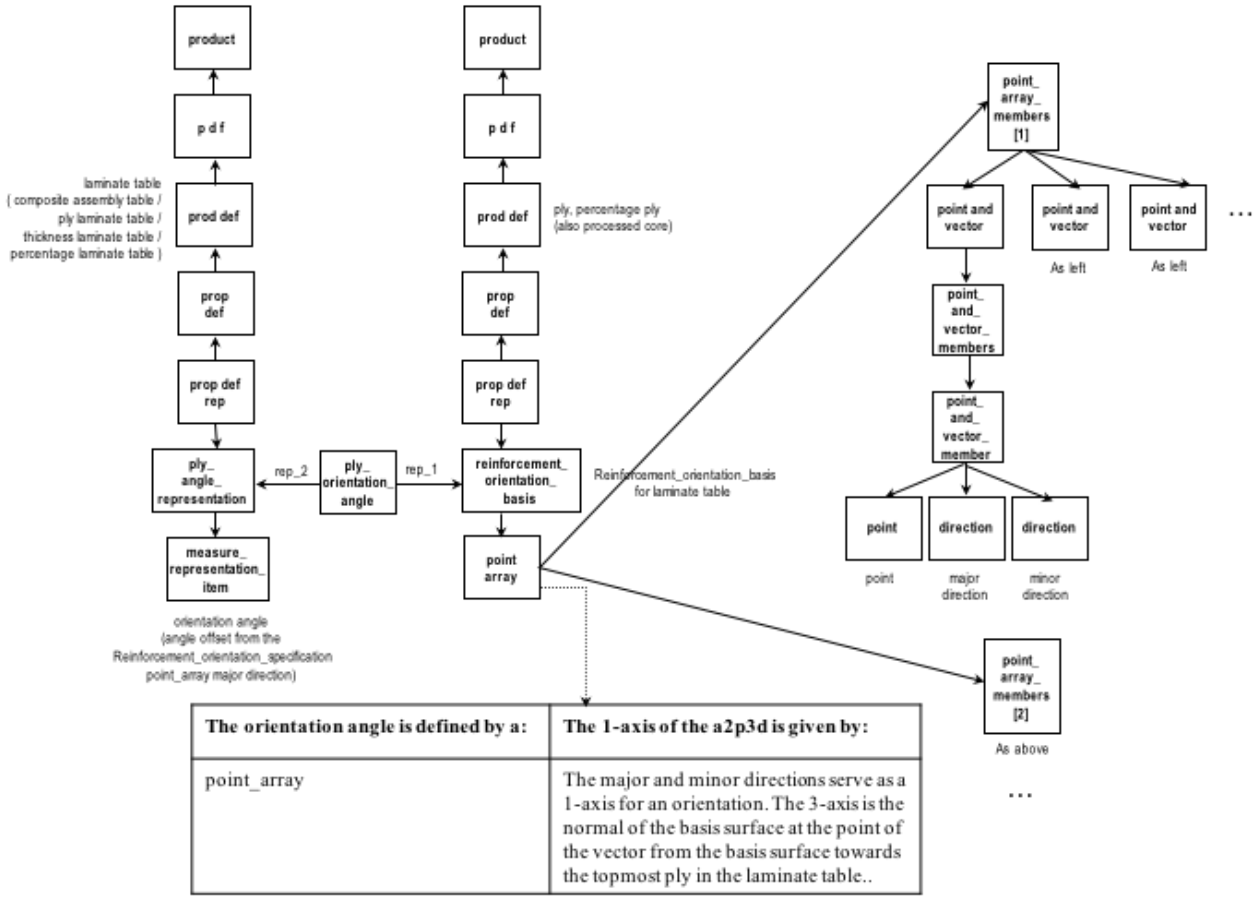


Figure 17: Ply Orientation by Point Array

NOTE: See Annex A for the abbreviations used in Figure 17.

Some composite structural modeling tools allow and/or require that a ply orientation angle be named. In this case the inherited `.name` attribute of the `cartesian_11, curve_11, cylindrical_11 or polar_11` entity shall be used for the name.

Alternately, the ply orientation may be specified implicitly through a user defined specification. This method allows a proprietary method to be specified (see Figure 18).

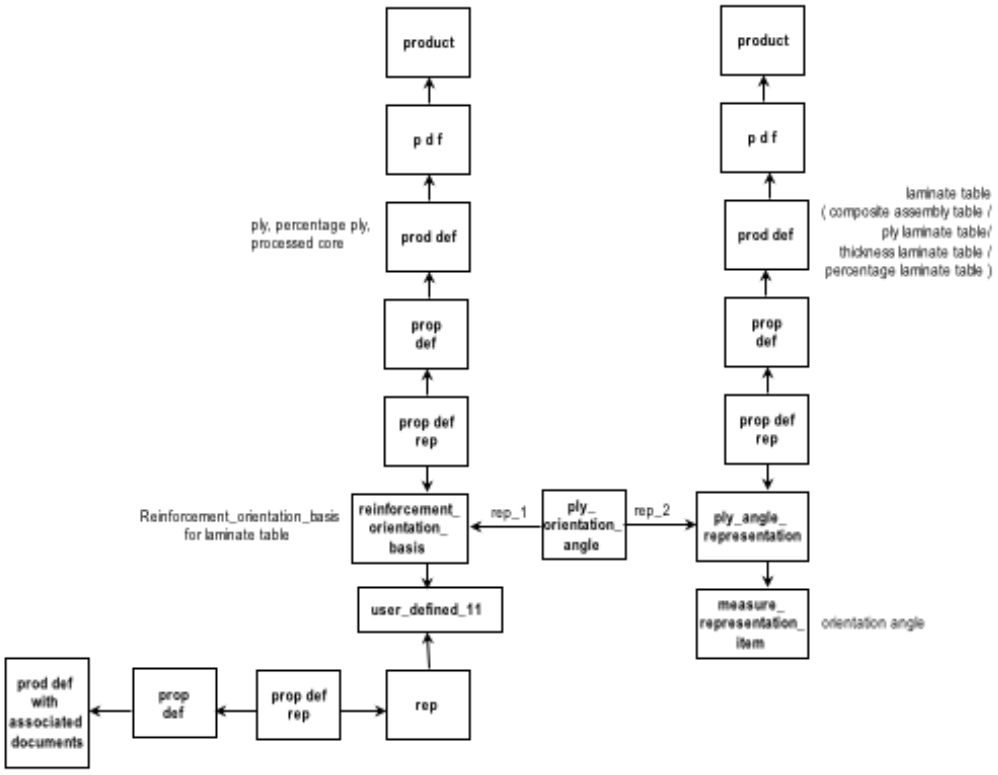


Figure 18: Ply Orientation by User Defined Specification

NOTE: See Annex A for the abbreviations used in Figure 18.

3.1.2.3 Ply Shape

The shape of a ply is represented by a `product_definition_shape` entity. `Shape_aspects` that represent various features of the ply shape point to this `product_definition_shape`. The `name` attribute of the `shape_aspect` shall describe the feature that is being represented, such as 'laid ply shape', 'basis surface', and 'outer edge'.

The shape of a ply may be a nominal design shape, or a manufacturing shape. Figure 19 illustrates these types of shapes.

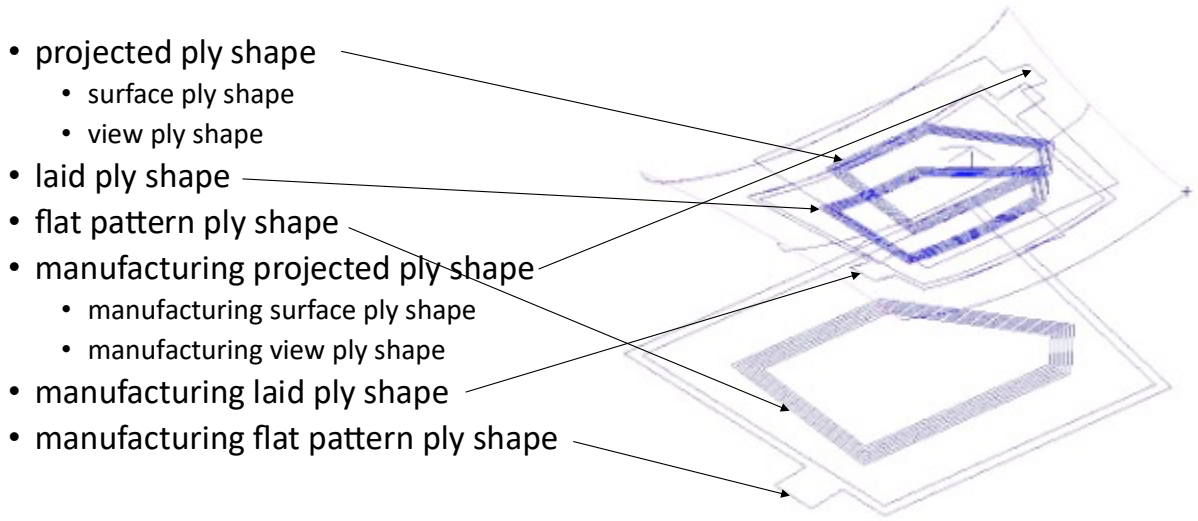


Figure 19: Types of Ply Shapes

The defining model for a ply shape is given by a `shape_representation` that is a `composite_sheet_representation`, an `advanced_brep_shape_representation`, a `csg_shape_representation`, a `curve_swept_solid_shape_representation`, an `elementary_brep_shape_representation`, a `tessellated_shape_representation`, or a `faceted_brep_shape_representation`. The `composite_sheet_representation` shall be either a `geometrically_bounded_surface_shape_representation` or a `manifold_surface_shape_representation` (Figure 20).

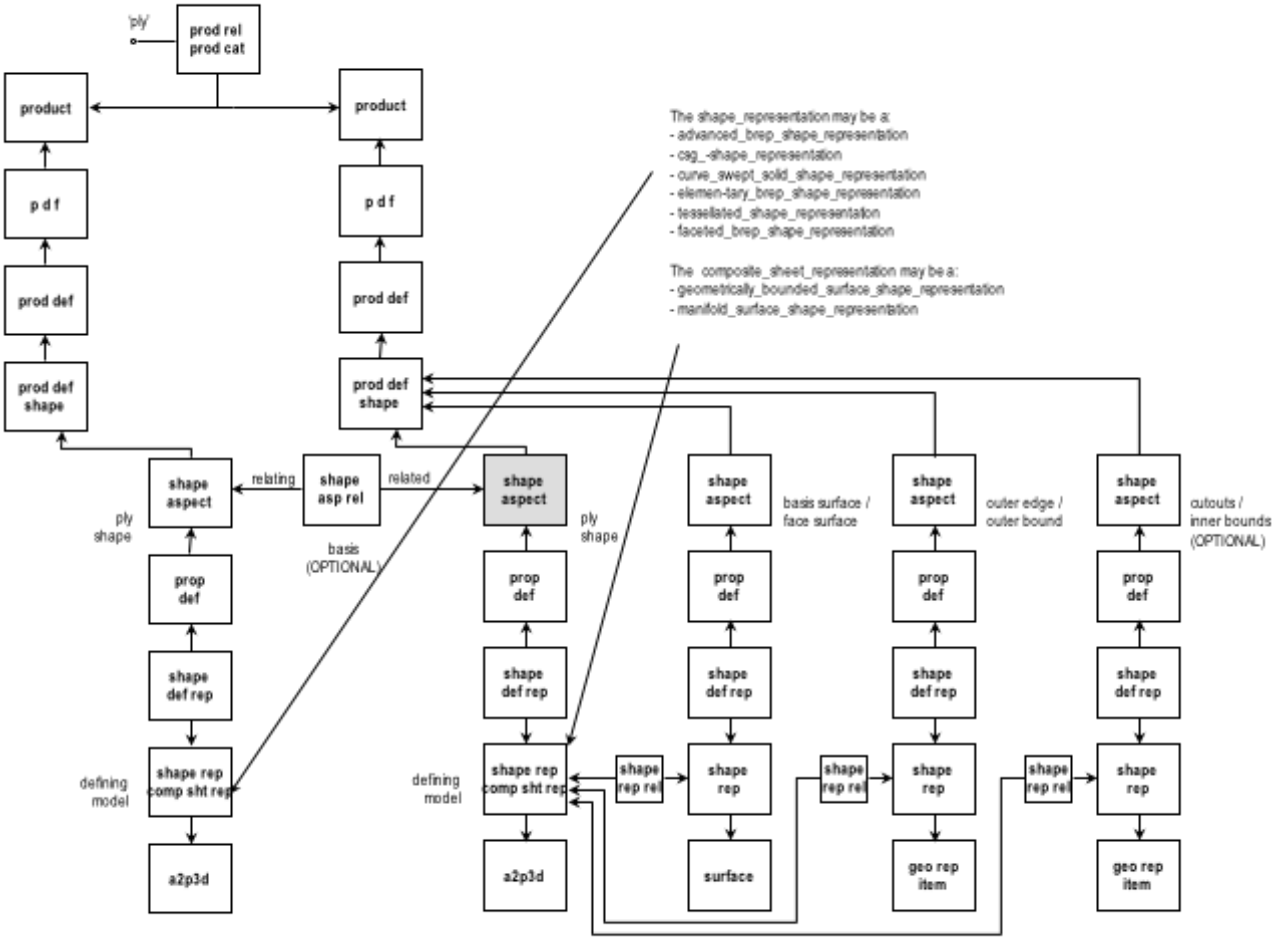


Figure 20: Ply Shape

NOTE: See Annex A for the abbreviations used in Figure 20.

Associated with the defining model `shape_representation` are the `shape_representations` for: a) the basis or face surface of the ply with a corresponding `shape_aspect.name` of 'basis surface' or 'face surface'; b) outer edge or bound of the ply with a corresponding `shape_aspect.name` of 'outer edge' or 'outer bound'; and, optionally, c) the cutouts or inner bounds for the ply with a corresponding `shape_aspect.name` of 'cutouts' or 'innerbounds'. Each of these `shape_representations` is related to the defining model `shape_representation` by a `shape_representation_relationship`.

If the shape of a ply is based on or derived from another ply shape, then this relationship is represented by a `shape_aspect_relationship` between the `shape_aspects` for the defining model `shape_representations` of the two plies. The `name` attribute of the `shape_aspect_relationship` is set to 'basis'.

A ply shape may be one of: laid ply shape, flat pattern ply shape, projected ply shape, manufacturing laid ply shape, manufacturing flat pattern ply shape, or manufacturing projected ply shape.

For a laid ply shape, the `name` of the `shape_aspect` for the defining model is set to 'laid ply shape' or 'manufacturing laid ply shape'.

For a flat pattern ply shape, the `name` of the `shape_aspect` for the defining model is set to 'flat pattern ply shape' or 'manufacturing flat pattern ply shape' (see Figure 21). The wrapup origin on the flat pattern is represented by the `location` attribute of the `placement` `representation_item` in the items of the flat pattern `shape_representation`. The wrapup origin on the flat pattern is represented by the `location` attribute of the `placement` `representation_item` in the `items` of the 3D `shape_-representation` from which the flat pattern is derived. The `shape_representations` are linked together by a complex entity that is a `flat_pattern_ply_representation_-relationship` and a `representation_relationship_with_transformation`. The `rep_1` attribute of the `representation_relationship_with_transformation` represents the 3D shape representation and the `rep_2` attribute is the flat pattern `shape_representation`. The `transformation_operator` attribute points to the `item_defined_transformation` entity that serves to match the origin points on the flat pattern and surface.

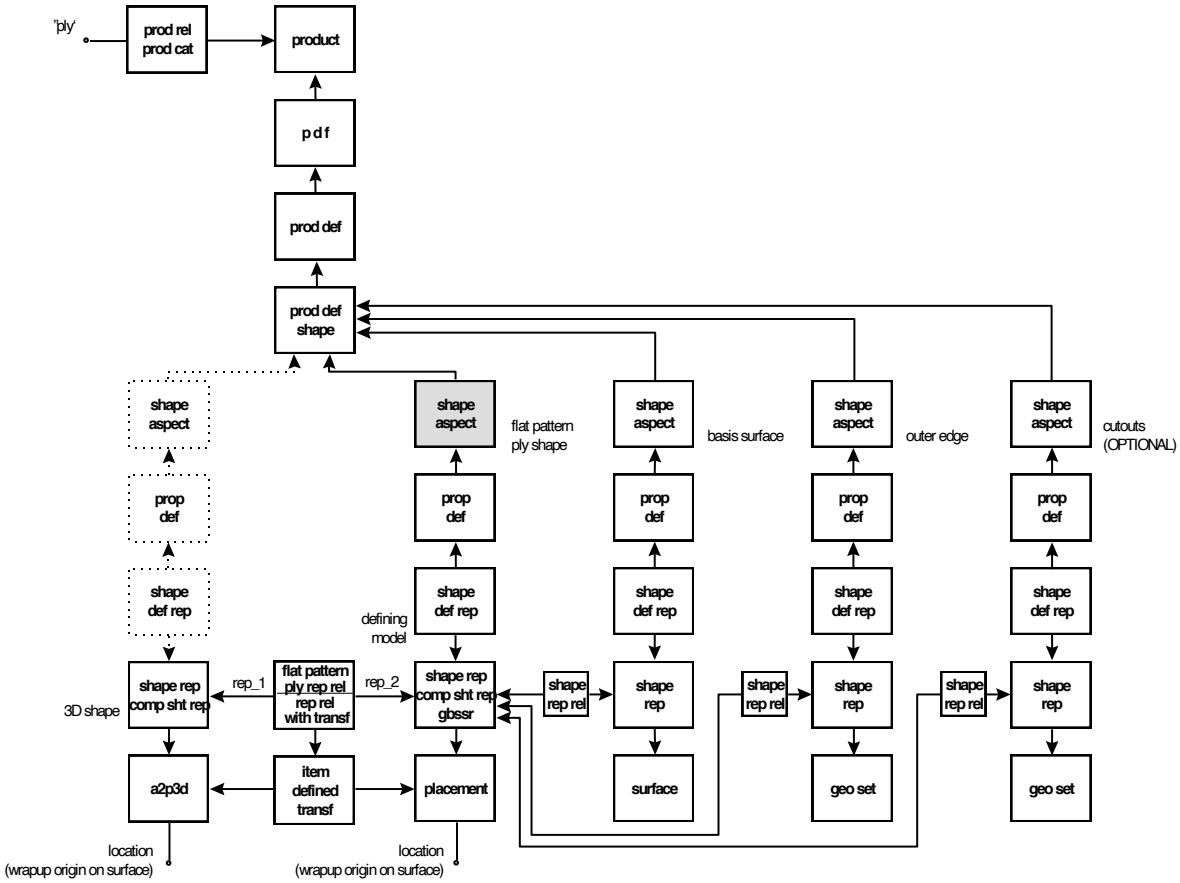


Figure 21: Flat Pattern Ply Shape

NOTE: See Annex A for the abbreviations used in Figure 21.

For a projected ply shape, the ply shape may be a surface ply shape or a view ply shape depending on whether the ply shape is projected on a surface or a plane. The `name` of the `shape_aspect` for the defining model is set to: 'reference direction projected surface ply shape', 'surface normal projected surface ply shape', 'reference direction projected view ply shape', 'surface normal projected view ply shape', 'manufacturing reference direction projected surface ply shape', 'manufacturing surface normal projected surface ply shape', 'manufacturing reference direction projected view ply shape', or 'manufacturing surface normal projected view ply shape' based on the projection method. If a direction other than the surface normal is used, a `shape_aspect` representing the projection

direction is associated with the `product_definition_shape`, and a `placement` entity referencing the projection direction is included in the set of items of the corresponding `shape_representation` (see Figure 22).

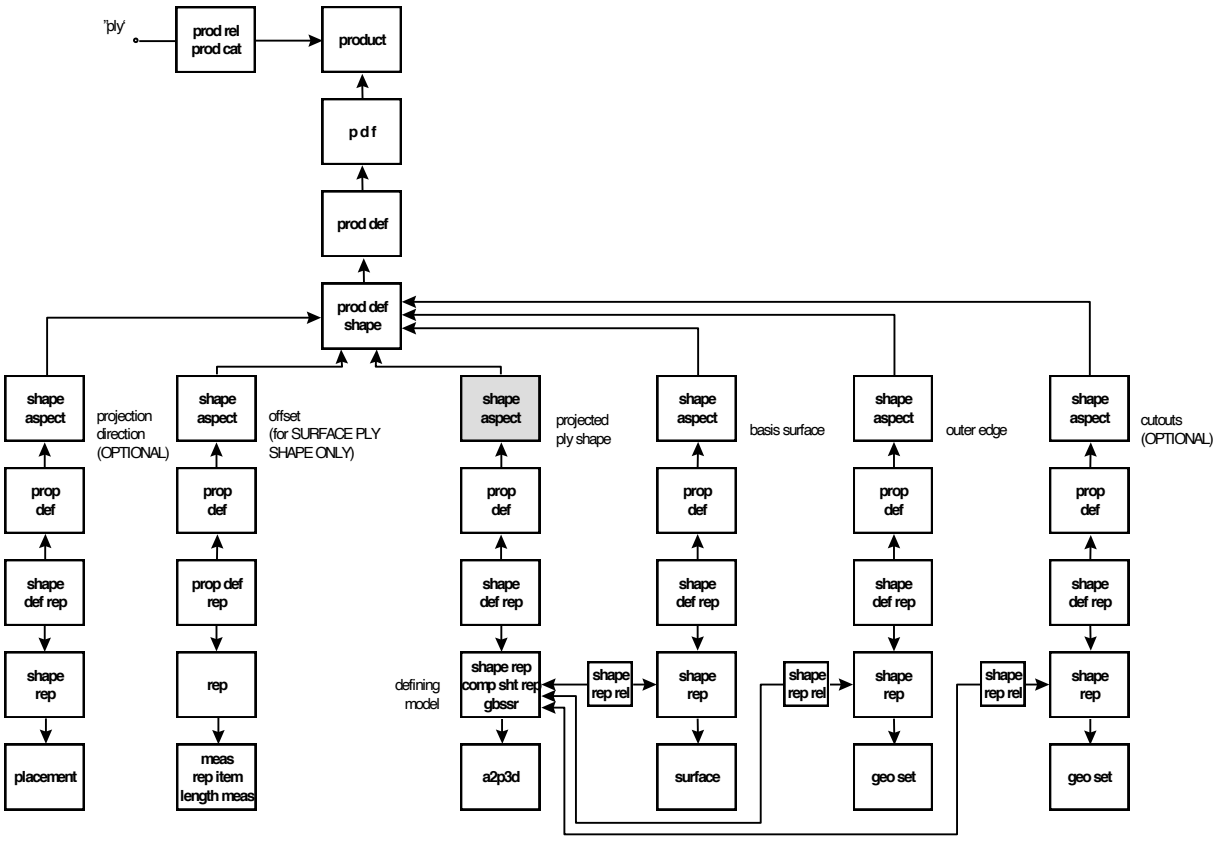


Figure 22: Projected Ply Shape (Surface Ply Shape or View Ply Shape)

NOTE: See Annex A for the abbreviations used in Figure 22.

For a surface ply shape, the context of the surface is indicated by the description attribute of the `shape_aspect` for the defining model. It is recommended that the description be set to: 'layup surface', 'outer mold line', or 'inner mold line'. The offset distance from the layup surface is represented by a separate `shape_aspect`. The corresponding representation shall have a `measure_representation_item` that is a `length_measure_with_unit` in its set of items.

3.1.2.4 Processed Core

A processed core product is associated with a `product_related_product_category` with a `name` of 'processed_core' (Figure 23, Figure 24).

The processed core `product_definition` is related by a `make_from_usage_option` entity to its stock material `product_definition`, which will be associated with a product in a `product_related_product_category` with a `name` of 'stock_core'.

Processed core may have one of two different types of shape representations. The first type of shape representation is a beveled sheet representation (Figure 23) that is a sheet with thickness

and beveled edges. The second type of shape representation is a solid model (Figure 24) where the core shape is a type of solid model. See ISO/TS 10303-1767:2014-02(E) Composite constituent shape clause 4.3 for more details on the types of processed core shape representations.

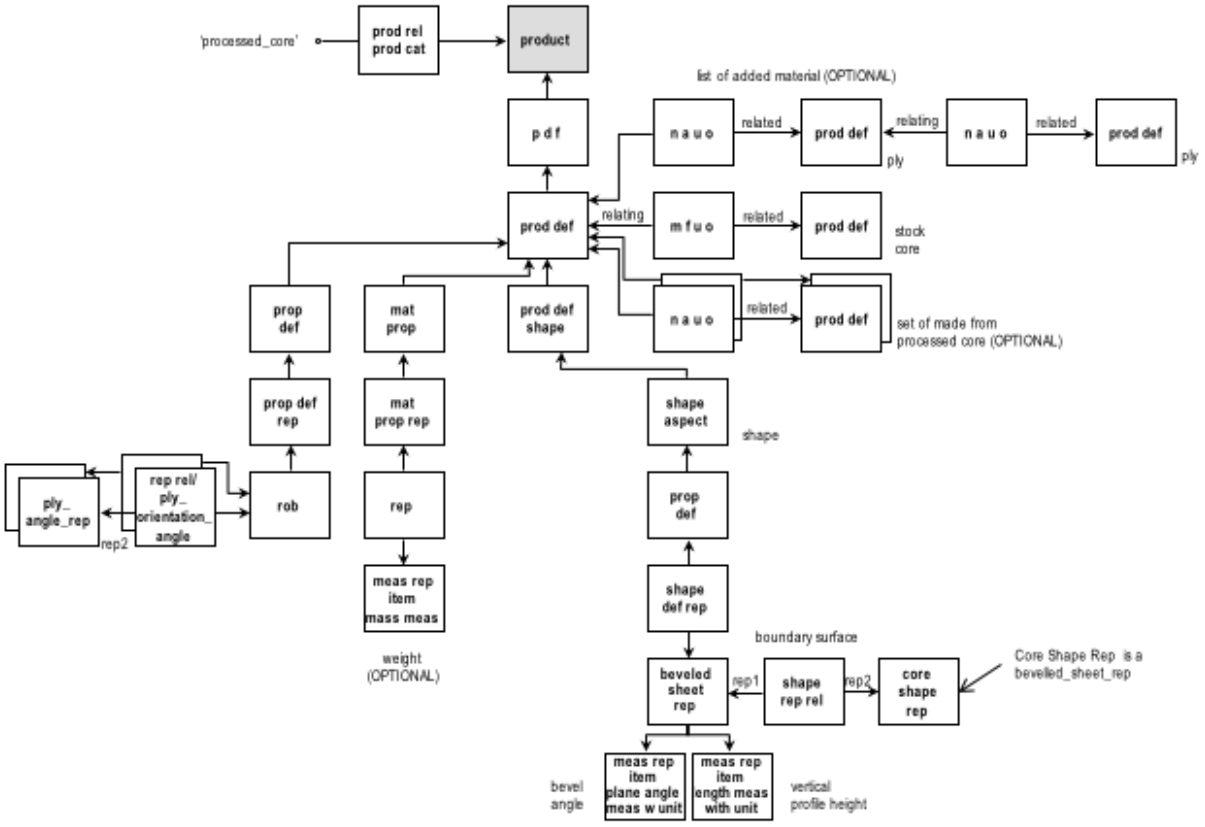


Figure 23: Processed Core – Beveled Sheet Representation Case

NOTE 1: See Annex A for the abbreviations used in Figure 23.

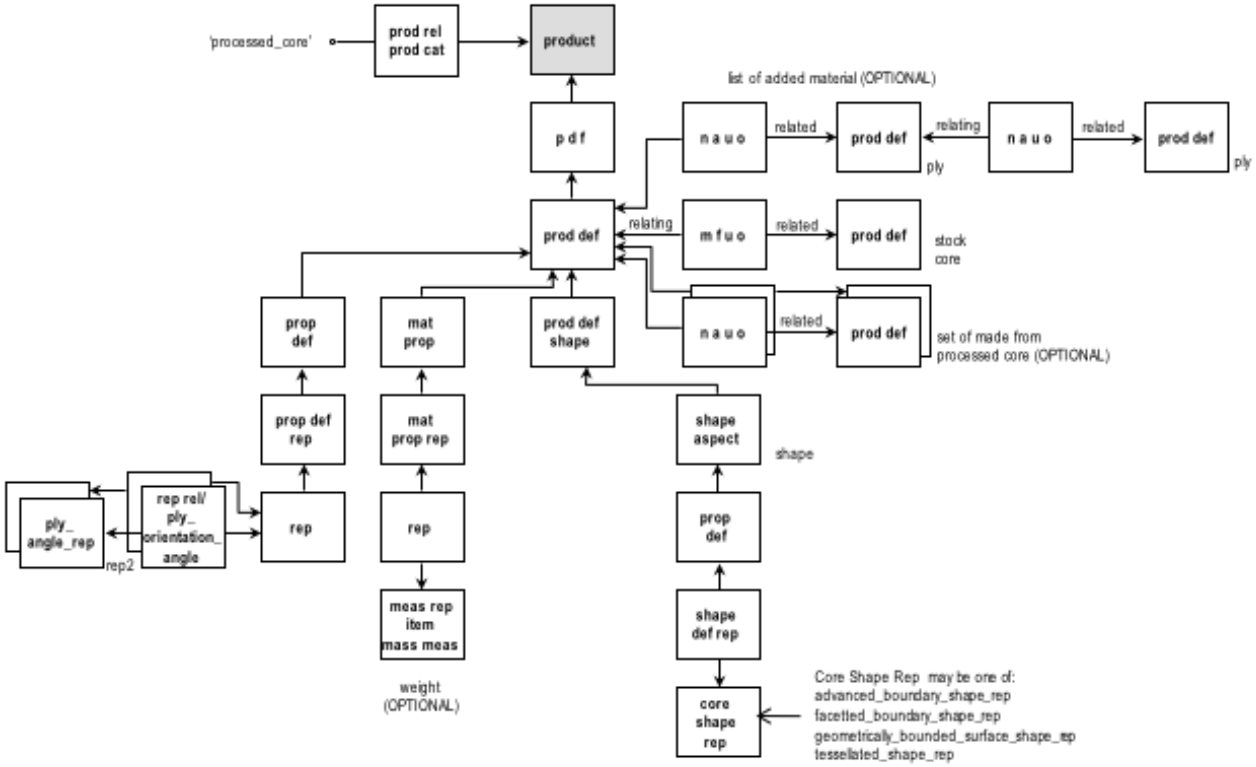


Figure 24: Processed Core – Solid Shape Representation Case

NOTE 2: See Annex A for the abbreviations used in Figure 24.

The list of any added material such as stabilizer, adhesive, and potting compound shall be given by a chain of `next_assembly_usage_occurrence` entities. The first `next_assembly_usage_occurrence` in the chain shall have the `product_definition` for the processed core as the `relating_product_definition`; the `product_definition` for the ply where the first added material in the list is applied shall be the `related_product_definition`. The successive `next_assembly_usage_occurrences` in the chain shall likewise link the `product_definitions` for the plies where subsequent added material in the list are applied.

If the processed core is made from one or more processed cores, then the `product_definitions` for the latter shall be related to that for the former by a set of `next_assembly_usage_occurrence` entities.

3.1.2.5 Core Orientation

A processed core has a cell orientation, i.e., the ribbon direction for the core. The orientation angle is derived in the manner described for a ply - see 3.1.2.2 for details.

3.1.2.6 Core Shape

The shape of a processed core may be represented by an `advanced_boundary_shape_representation`, `faceted_boundary_shape_representation`, `geometrically_bounded_surface_shape_representation`, a `tessellated_representation` or a `beveled_sheet_representation`. A `beveled_sheet_representation` is a subtype of `shape_representation` whose base boundary surface is based on a `composite_sheet_representation`. Two `measure_representation_items` characterize a `beveled_sheet_representation`. The first `measure_representation_item` in its set of `items` is a `plane_angle_measure_with_unit` representing the angle between the surface normal of the base surface to the beveled surface. The second is a `length_measure_with_unit` representing the height of the core measured vertically from the base surface.

3.1.2.7 Filament Laminate

A filament laminate product is associated with a `product_related_product_category` with a `name` of 'filament_laminate' (Figure 25). The filament laminate `product_definition` is related by a `make_from_usage_option` entity to its filament assembly `product_definition`, which will be associated with a `product` in a `product_related_product_category` with a name of 'filament_assembly'.

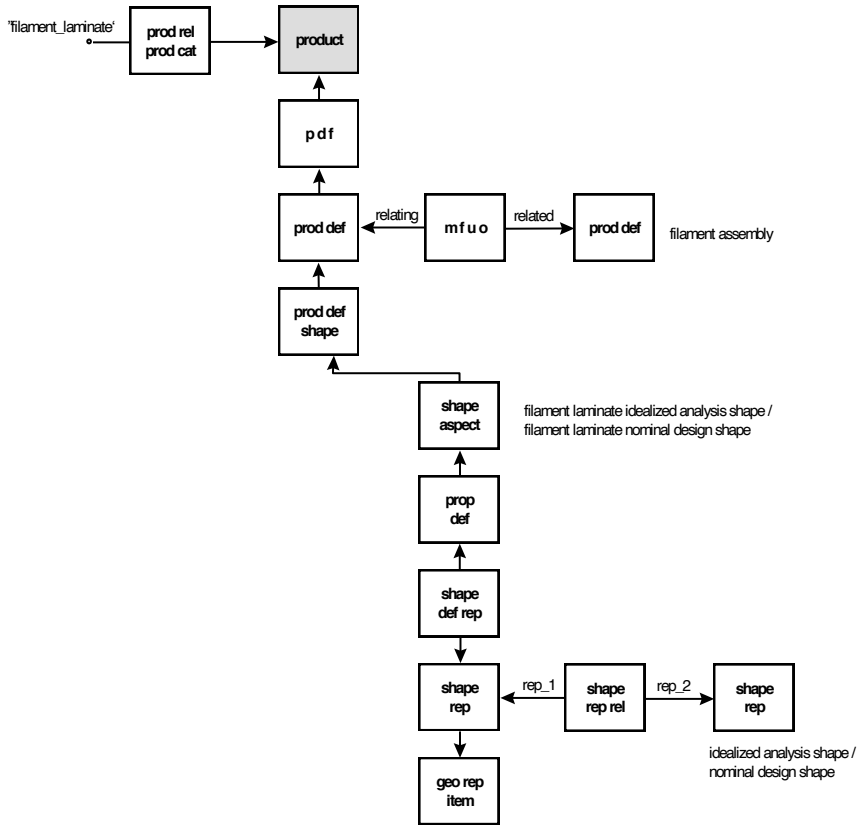


Figure 25: Filament Laminate

NOTE: See Annex A for the abbreviations used in Figure 25.

The shape of a filament laminate is given by a `shape_representation` for its cross section. This `shape_representation` is related to the nominal design or idealized analysis `shape_representation` through a `shape_representation_relationship`. The `name` of the `shape_aspect` is set accordingly to 'filament_laminate_nominal_design_shape' or 'filament_laminate_idealized_analysis_shape'.

3.1.2.8 Ply Laminate

A ply laminate product is associated with a `product_related_product_category` with a name of 'ply_laminate' (Figure 26). The ply laminate `product_definition` is related by a `make_from_usage_option` to the `product_definition` for the ply laminate table that is represented by a `ply_laminate_table` (see 3.1.1.1).

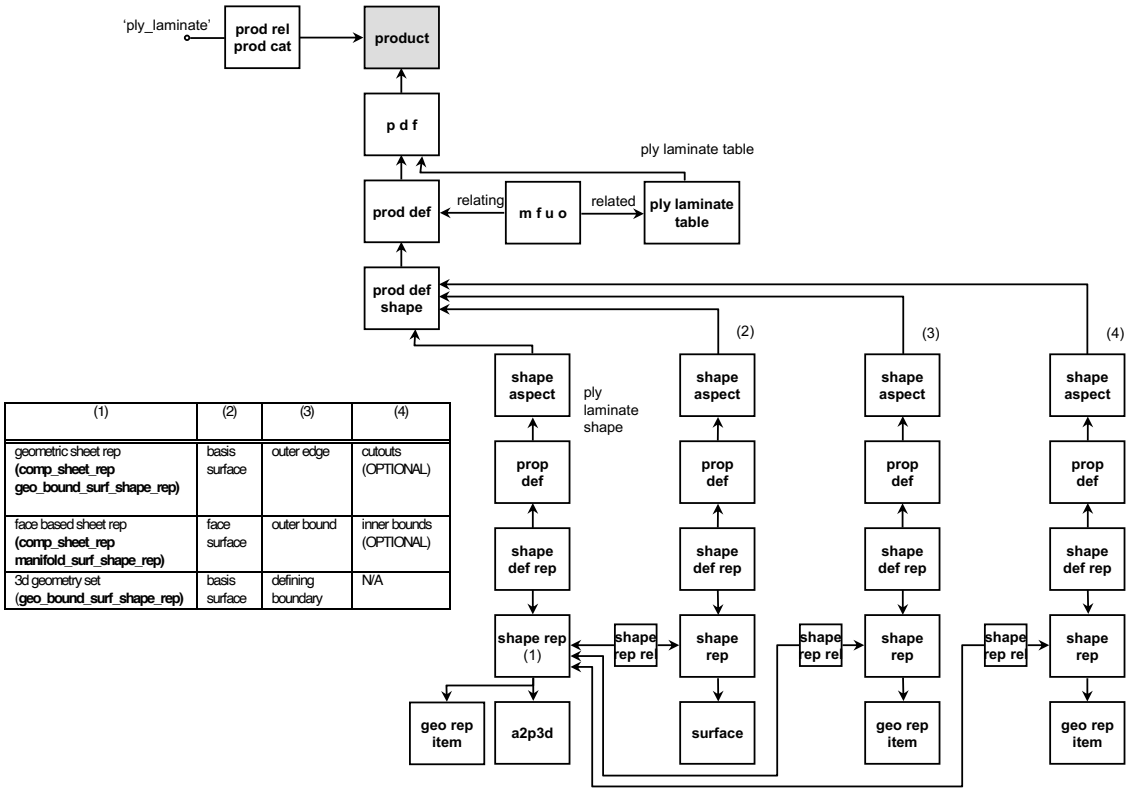


Figure 26: Ply Laminate

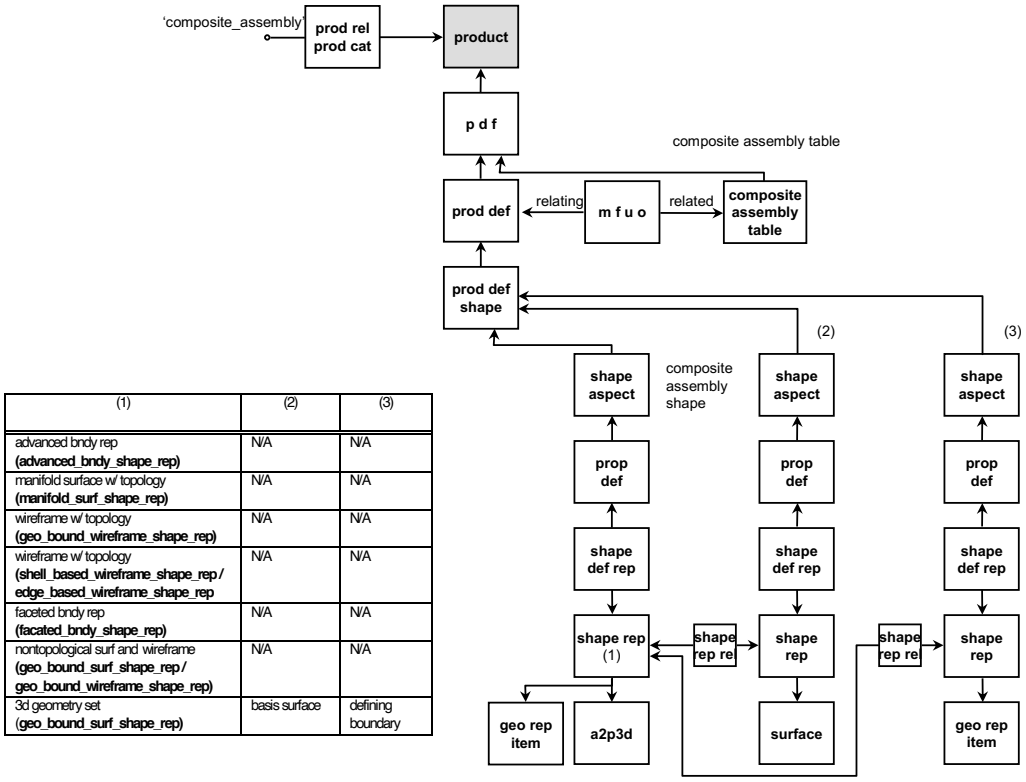
NOTE: See Annex A for the abbreviations used in Figure 26.

The shape of a ply laminate may be represented by a `composite_sheet_representation` or a 3D geometry set. The `composite_sheet_representation` shall be a `geometrically_bounded_surface_shape_representation` or a `manifold_surface_shape_representation`. Associated with the `composite_sheet_representation` are `shape_representations` for the basis or face surface of the ply laminate, outer edge or bound of the ply laminate, and optionally the cutouts or inner bounds for the ply laminate (see 3.1.2.8 for the respective `shape_aspect.name` values). Each of these `shape_representations` is related to the ply laminate `shape_representation` by a `shape_representation_relationship`.

A 3D geometry set shape is represented by a `geometrically_bounded_surface_shape_representation` entity. Associated with this `shape_representation` are `shape_representations` for the basis surface of the ply laminate (`shape_aspect.name` of 'basis_surface') and the defining boundary of the ply laminate (`shape_aspect.name` of 'defining_boundary'). The context of the basis surface is indicated by setting the description attribute of the corresponding `shape_aspect` to 'layup_surface', 'outer_mold_line', or 'inner_mold_line'.

3.1.2.9 Composite Assembly

A composite assembly product is associated with a `product_related_product_category` with a name of 'composite_assembly' (Figure 27). The composite assembly `product_-definition` is related by a `make_from_usage_option` to the `product_definition` for the composite assembly table, represented by a `composite_assembly_table` (see 0).



(1)	(2)	(3)
advanced bndy rep **(advanced_bndy_shape_rep)**	N/A	N/A
manifold surface w/ topology **(manifold_surf_shape_rep)**	N/A	N/A
wireframe w/ topology **(geo_bound_wireframe_shape_rep)**	N/A	N/A
wireframe w/ topology **(shell_based_wireframe_shape_rep / edge_based_wireframe_shape_rep**	N/A	N/A
faceted bndy rep **(facated_bndy_shape_rep)**	N/A	N/A
nontopological surf and wireframe **(geo_bound_surf_shape_rep / geo_bound_wireframe_shape_rep)**	N/A	N/A
3d geometry set **(geo_bound_surf_shape_rep)**	basis surface	defining boundary

Figure 27: Composite Assembly

NOTE: See Annex A for the abbreviations used in Figure 27.

The shape of a composite assembly may be represented by one of the following shape representations: advanced or faceted boundary representation (`advanced_boundary_shape_representation` or `faceted_boundary_shape_representation`); manifold surface with topology (`manifold_surface_shape_representation`); wireframe with topology (`shell_based_wireframe_shape_representation` or `edge_based_wireframe_-shape_representation`); nontopological surface and wireframe (`geometrically_-bounded_surface_shape_representation` or `geometrically_bounded_wireframe_-shape_representation`); or a 3D geometry set (`geometrically_bounded_surface_-shape_representation`).

3.1.3 Materials and Properties

Stock material is treated as a product in AP 203 ed2, AP 209 ed2 and AP242. A stock material product shall be among the `products` of a `product_related_product_category` with a name of : 'isotropic_material', 'anisotropic_material', 'filament_assembly', 'discontinuous_fiber_assembly', 'braided_assembly', 'woven_assembly', or 'stock_core' (Figure 28). The stock_material `product_definition` may have an `approval` in AP 203 ed2, AP 209 ed2 and AP242.

Material properties, including finite element analysis material properties, are represented by the `property_definition` subtype `material_property`. The name attribute inherited from the `property_definition` supertype is used to denote the particular property being qualified or quantified. The `material_property_representation` entity links a `material_property` to a `representation` that may contain a `measure_representation_item` in its set of `items` to provide a quantitative value the property.

Conditions such as temperature and moisture content that relate to the material properties are grouped in a `data_environment` that is referenced by the `material_property_representation` entities as their `dependent_environment`. The `representation` for each condition is associated with the stock material through a `property_definition`. The `representation` of a material reference direction is likewise associated with the stock material through a `property_definition`.

3.1.3.1 Material Specifications

Material specifications that are applicable to a stock material are related to the stock material `product_definition` through an `applied_document_reference` entity. The stock material `product_definition` is contained in the items of the `applied_document_reference`. The `assigned_document` attribute inherited from the `document_reference` supertype of `applied_document_reference` points to the specification `document` (Figure 28).

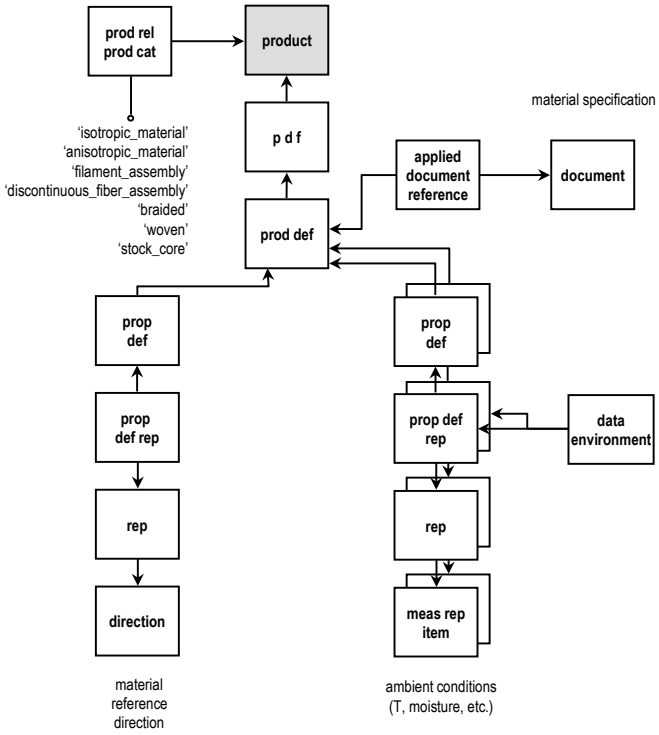


Figure 28: Stock Material

NOTE: See Annex A for the abbreviations used in Figure 28.

3.1.3.2 Material Callout

The designation of the material for a part is accomplished through a `make_from_usage_option` entity. The `make_from_usage_option.relating_product_definition` shall be the 'design discipline' `product_definition` for the part. If the component part or the composite constituent is produced from a single material, then the `make_from_usage_option.related_product_definition` shall be the `product_definition` for the material (such as an 'isotropic material', 'anisotropic material', or 'filament assembly'). If the component part is a composite, the `make_from_usage_option.related_product_definition` shall be the `product_definition` for the laminate table representation (e.g., `ply_laminate_table`, `composite_assembly_table`, or `thickness_laminate_table`).

4 Geometric Founding of Composite Constituent Product Definitions

The simplest case for composite constituent product definitions is when all product definitions use the same `representation_context`. No transformations are required for the simplest case. This applies to a Laminate Table subtype and to any Ply or Composite Constituent shape representations.

This is by far the most frequently instantiated case.

4.1 Referenced Shape in an Assembly with Additional Laminate Table Representation

Figure 29 represents the case where the laminate table subtype is founded with respect to the component/detail within an assembly. Note that it is not required for the component/detail be in an assembly, and that the laminate table subtype could also be related to the assembly.

This is the second most frequently instantiated case.

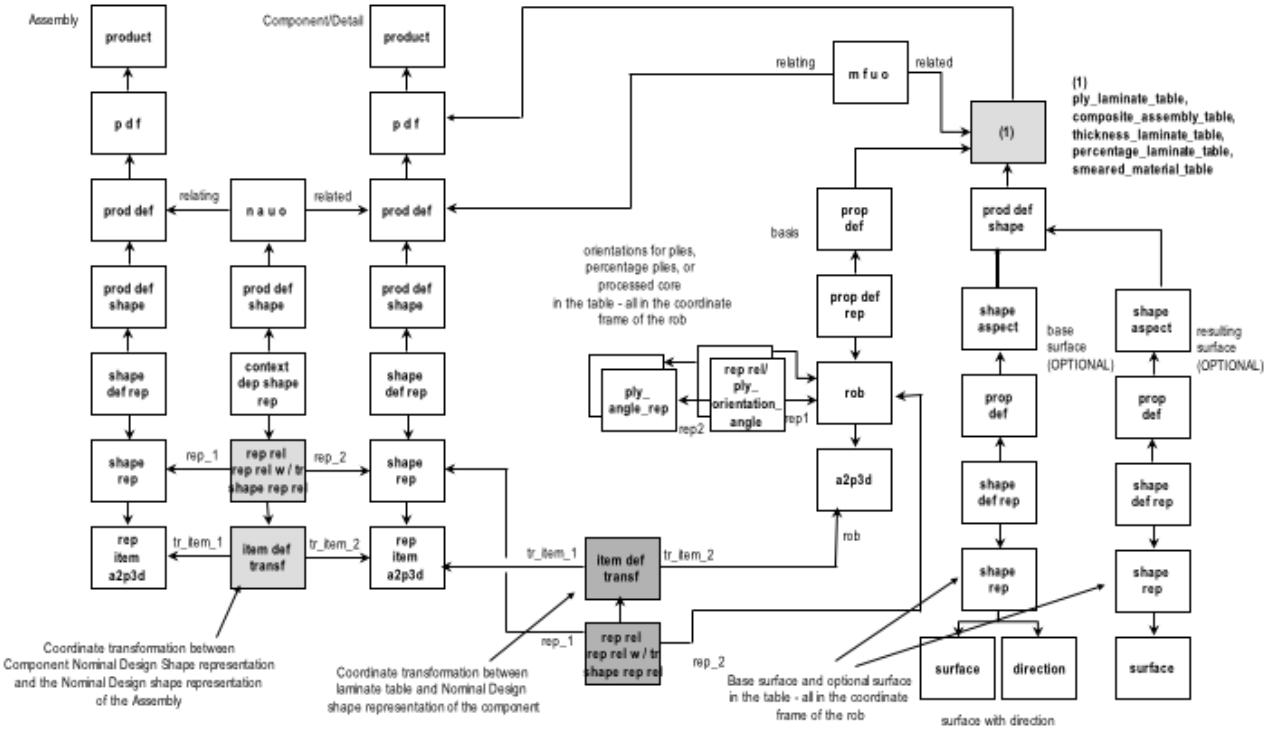


Figure 29: Referenced Shape in an Assembly with Additional Laminate Table Representation - Most General Geometric Founding Case

NOTE: See Annex A for the abbreviations used in Figure 29.

4.2 Founding of Ply Subtypes and Composite Constituents with Respect to a Laminate Table subtype – the Most General Case

The Ply shape subtypes and Composite Constituent shapes listed in Table 3 represent the different types of shape indicated on the right – hand side of Figure 30. Any of these shapes may be founded with respect to each other, or with respect to the Laminate Table subtype that they are a member of.

This is a rarely instantiated case included for completeness.

Laid Ply Shape
Flat Pattern Ply Shape
Projected Ply Shape – Surface Ply Shape
Projected Ply Shape – View Ply Shape
Processed Core Shape
Filament Laminate Shape
Ply Laminate Shape
Composite Assembly Shape

Table 3: Ply Subtypes and Composite Constituents

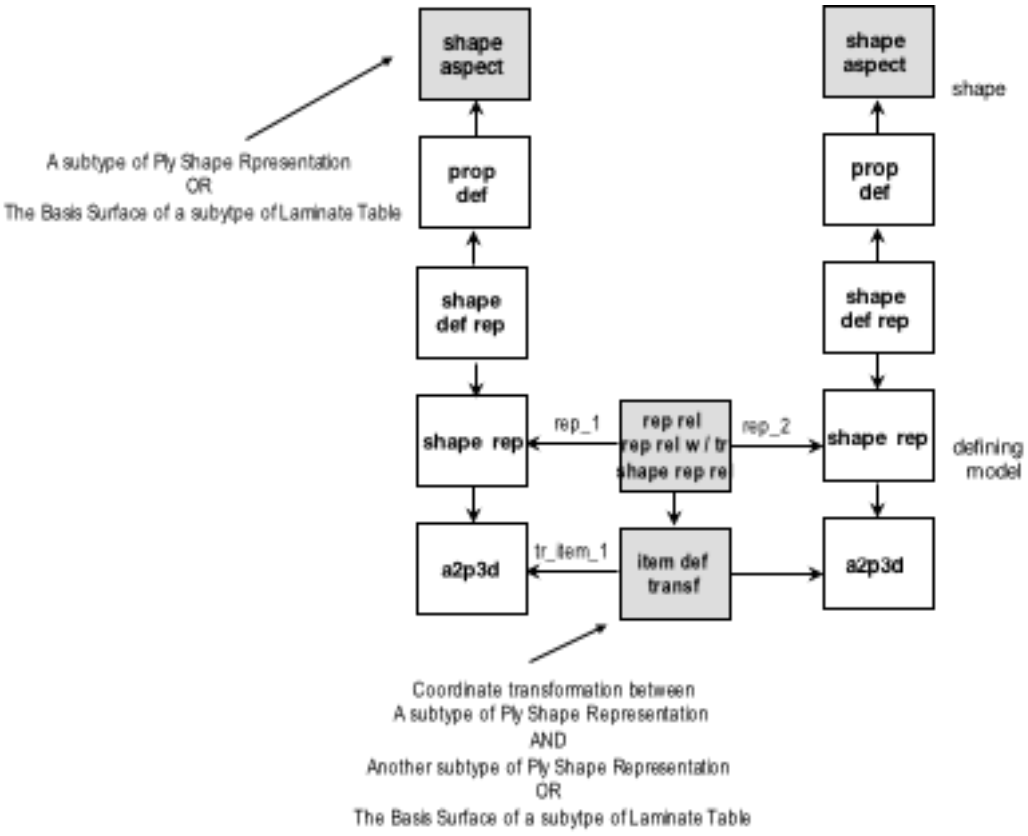


Figure 30: Founding of Ply and Composite Constituent Shapes - Most General Case

NOTE: See Annex A for the abbreviations used in Figure 30.

Annex A Abbreviations used in Instantiation Diagrams

Abbreviation	Entity Type
a2p3d	axis2_placement_3d
beveled sheet rep	beveled_sheet_representation
comp assy seq def composite assembly seq def	composite_assembly_sequence_definition
comp sht rep comp sheet rep	composite_sheet_representation
composite assembly table	composite_assembly_table
fea mat prop rep	fea_material_property_representation
fea mat prop rep item	fea_material_property_representation_item
flat pattern ply rep rel	flat_pattern_ply_representation_relationship
gbssr geo bound surf shape rep	geometrically_bounded_surface_shape_representation
geo rep item	geometric_representation_item
geo set	geometric_set
item defined transf	item_defined_transformation
length meas	length_measure
length meas w unit	length_measure_with_unit
m f u o	make_from_usage_occurrence
mass meas	mass_measure
mat prop	material_property
mat prop rep	material_property_representation
meas rep item	measure_representation_item
mssr manifold surf shape rep	manifold_surface_shape_representation
n a u o	next_assembly_usage_occurrence
p d f	product_defintion_formation
percentage laminate table	percentage_laminate_table
percentage ply def	percentage_ply_definition
plane angle meas w unit	plane_angle_measure_with_unit
ply angle rep	ply_angle_representation
ply laminate seq def	ply_laminate_sequence_definition
ply laminate table	ply_laminate_table
prod def	product_defintion
prod def shape	product_definition_shape

Abbreviation	Entity Type
prod def with associated documents	product_definition_with_associated_documents
prod rel prod cat	product_related_product_category
prop def	property_definition
prop def rep	property_definition_representation
ratio meas	ratio_measure
rep	representation
rep item	representation_item
rep rel	representation_relationship
rep rel w/ tr rep rel with transf	representation_relationship_with_transformation
rob	reinforcement_orientation_basis
shape asp rel	shape_aspect_relationship
shape def rep	shape_definition_representation
shape rep	shape_representation
shape rep rel	shape_representation_relationship
smeared material definition	smeared_material_definition
thickness lam table	thickness_laminate_table

Annex B Availability of implementation schemas

B.1 AP242 Edition 2

The long form EXPRESS schema for the first edition of AP242 (2020) can be retrieved from:

- https://www.cax-if.de/documents/ap242ed2_mim_lf_v1.101.exp