ESAComp Training

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The software by Componeering

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ESAComp 培训大纲

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

BACKGROUND

- ESAComp与复合材料相关背景
- ESAComp操作与数据管理
- 复合材料单层设计与分析
- 复合材料纤维与基体设计与分析
- 复合材料层合板设计与分析
- 复合材料梁、板、加筋板结构分析
- 复合材料结构连接分析
- ESAComp有限元接口(Patran/Nastran协同操作)

ESAComp 背景

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

BACKGROUND

- 最早于1990年由欧洲航天局(European Space Agency， ESA/ESTEC)开发
- 背景与需求动机
  - 欧洲航天局为了自己
    的复合材料分析设计软件工具。
  - 急需一种基于单一标准，集成各个独立的软件工具，且具有统一图形化用户界面的软件工具。

ESAComp 背景

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

BACKGROUND

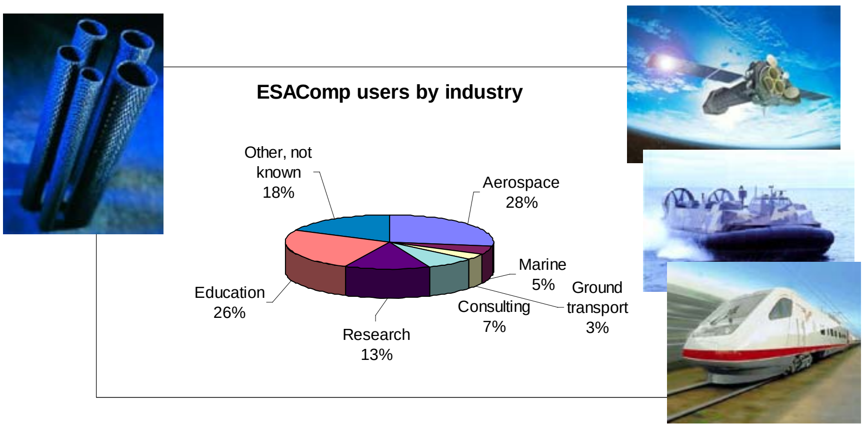
- 自1992年开始，由芬兰赫尔辛基工业大学轻型结构试验室开发
- 1998年发布ESAComp 1.0 版
- 2000年交由 Componeering公司进行商业推广
- 欧洲航天局（ESA）继续支持 ESAComp 的开发

Photo courtesy of ESA

ESAComp 应用现状

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

BACKGROUND

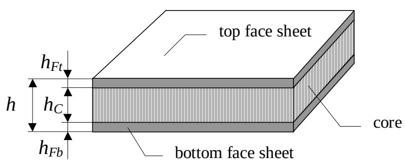


复合材料的优缺点

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

BACKGROUND

- 优点
  - 高比刚度
  - 高比强度
  - 优越的抗疲劳特性
  - 良好的环境适应能力
  - 可设计性
  - ……



复合材料的优缺点

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

BACKGROUND

- 缺点
  - 高性能复合材料价格昂贵
  - 制造成本高
  - 设计复杂、困难
  - 只有熟练掌握各向异性材料性能才能充分发挥法和材料的潜力
- 因此
  - 只有熟练掌握各向异性材料性能才能充分发挥法和材料的潜力
  - 在复合材料应用中特别强调 **"设计"**

复合材料分析设计的难点

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

BACKGROUND

- 各向异性的材料属性
- 层合结构
- 多尺度的协同效应
- 复杂的失效模式
- 纤维、基体、夹芯材料的选择
- 材料组合形式
- 铺层形式
- 材料性能的离散性
- ……

有限元软件的复合材料分析现状

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

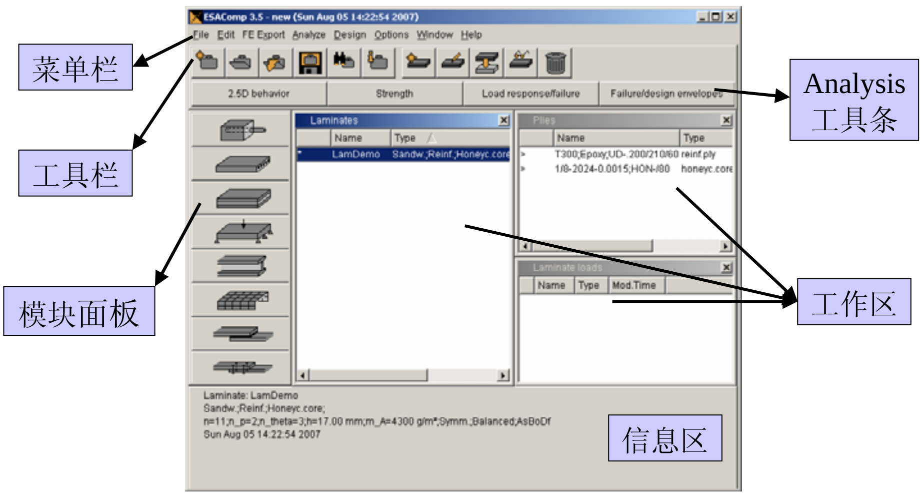
BACKGROUND

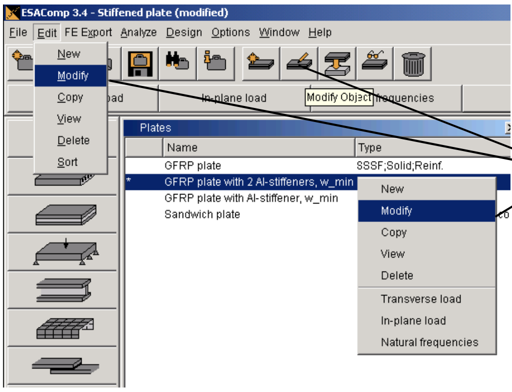
- 具有专门用于复合材料分析的各向异性壳单元模型
- 提供全局性的载荷分布和动态响应分析
- 单元级别的应力分布分析
- 后处理能力不足 (单层级别应力分布, 失效模式,…)
- 复合材料特定结构分析设计能力弱，建模复杂
- ……

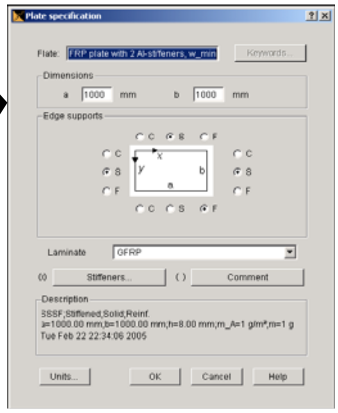
ESAComp 操作

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

ESAComp Operation



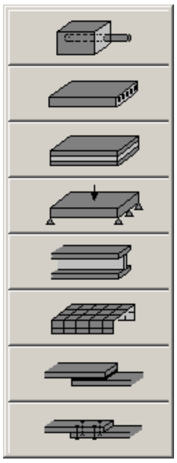




■提供了多样、方便、快捷的操作方法去完成工作。

ESAComp 操作
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
ESAComp Operation

模块面板



Fibers and Matrices 纤维和基体

Plies 单层

Laminates 层合结构

Plates 板

Beams 梁

FE Imports 有限单元输入

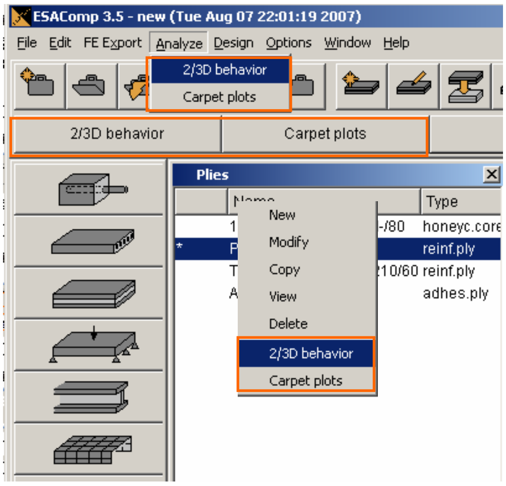
Bonded Joints 粘胶连接

Mechanical Joints 机械连接

ESAComp 操作

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

ESAComp Operation

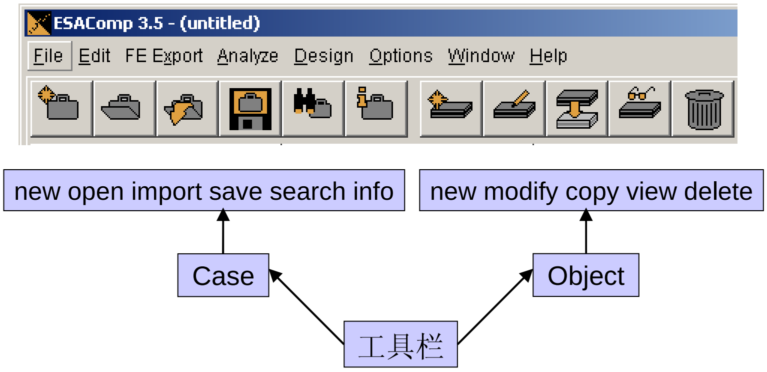


- Analysis工具条为进行典型常用分析提供方便操作
- Analysis工具条针对各个模块窗口专门设计

ESAComp 操作

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

ESAComp Operation



数据管理 Case和Object

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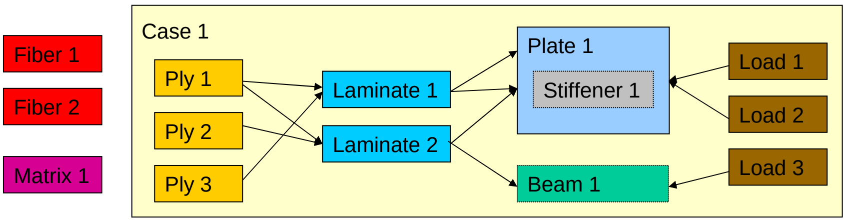
- Case是项目文件，是文件操作和储存的单元。
- 一个Case项目保存到单一数据文件中 (*.edf = ”ESAComp data file”)
  - 注意: Free edge FE analysis 结果是独立的文件
- Case是由一系列的 Object组成的研究计划。
- 具有相互关系的Object必须位于同一个Case中



数据管理 Case和Object

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

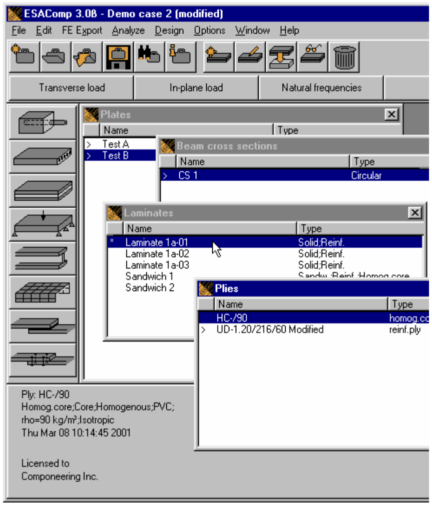
- ESAComp 的Object对象包括:
  fibers, matrix materials, plies, laminates, laminated structural elements (plates, beam cross sections, joints), loads associated with laminates and structural elements, FE import data sets
- 纤维\基体材料和细观力学生成的单层板并没有什么直接联系
  - 在单层板关键字注释里会包含所用的纤维\基体材料
  - 今后，将引入单层板与其纤维\基体材料之间的相互关联（比如：提示关联信息、根据纤维含量的改变更新单层板的性能）

数据管理 Case和Object

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Database Structure

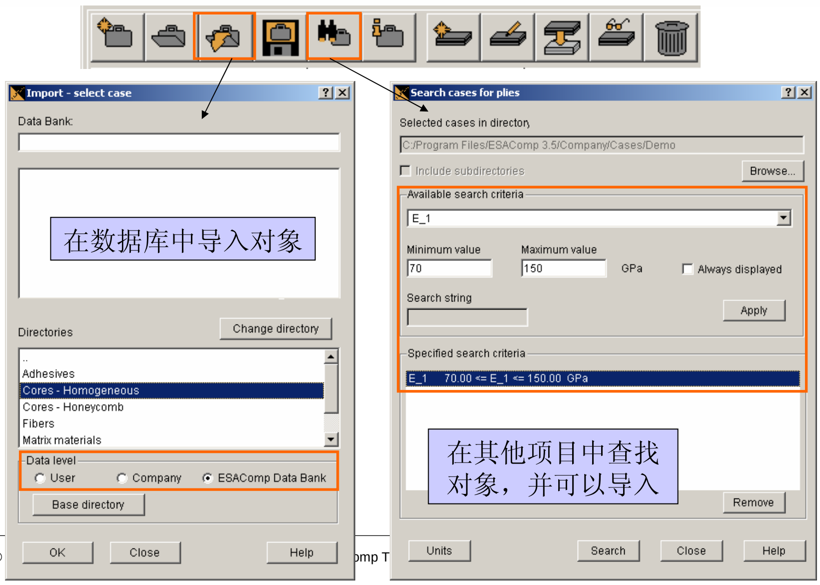
- 当选中一个对象的时候 (用*号标记)，与之相关的对象都会用 ">" 号高亮显示。
- 对象属性的修改会自动反映到相关联的其他对象中，除了给出提示消息外，关联对象的修改时间也同时改变。



数据管理 Case和Object

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Database Structure



数据管理 Case和Object

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Database Structure

- ESAComp 数据库分为三个级别:

(1) User level (2) Company level (3) ESAComp Data Bank

- 企业级数据指用户单位的专有材料、项目数据等;
- 每一个级别的数据库都对应一个专用存储路径;
- Company 级数据可存储于网络路径下 ;
- 在多用户系统中，各个用户可以单独定义自己的User级别数据路径。

数据管理 Case和Object

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Database Structure

- ESAComp Data Bank 数据库包含在软件系统内，由软件供应商提供。
  - 擅自改变系统Date Bank级别的数据会为今后的软件升级带来不便，因此我们建议用户不要将用户和企业级别的数据存储到Date Bank 级别中。
- Data Bank收录数据原则
  - 只收录可靠来源的数据
  - 将多个来源的数据看作“typical data ” (数据较为全面、完整)
- Data Bank主要数据来源
  - 材料供应商
  - 手册 (ESA, MIL-HDBK-17)
  - 出版物

数据管理 Case和Object

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Database Structure

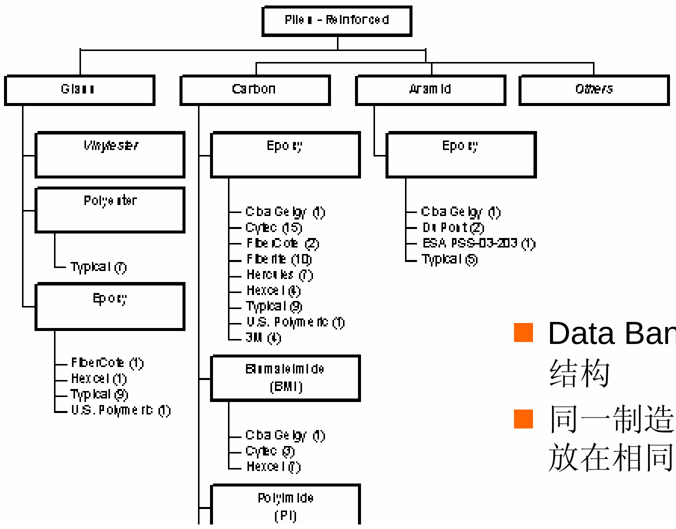
- Data Bank organization – first level

Data Bank
- Adhesives
- Cores-Homogenous
- Cores-Honeycomb
- Fibers
- Matrix materials
- Plies-Homogenous
- Plies-Reinforced

数据管理 Case和Object

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Database Structure



- Data Bank 树状结构
- 同一制造商产品放在相同目录下

数据管理 Case和Object

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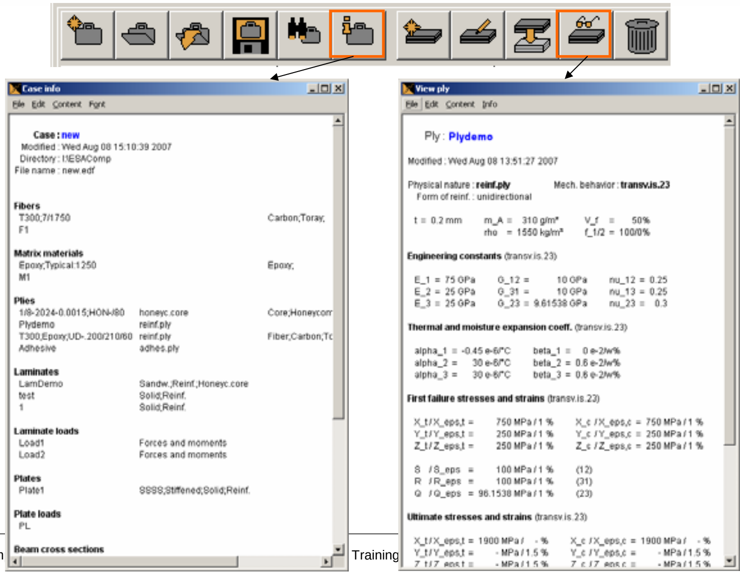
Database Structure



练习

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

- 从Company级数据库Micromechanics demo项目中导入一种纤维材料
- 从ESAComp data bank中导入一种基体材料
- 保存项目(case)
- 在Company级数据库中查找一种E1杨氏模量大于180GPa的单层(Ply),并选择一种T300材料导入当前项目(case)

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Specify a Ply 定义单层

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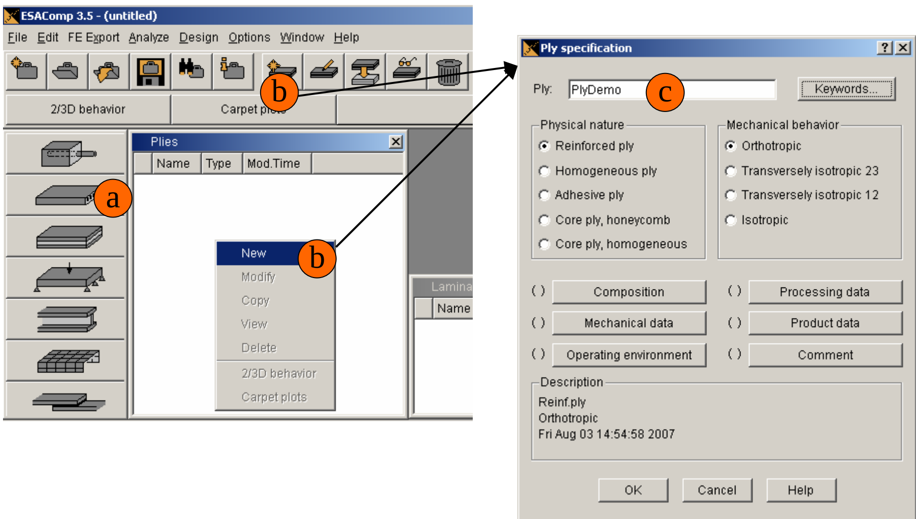
Specify a Ply



Specify a Ply 关键字

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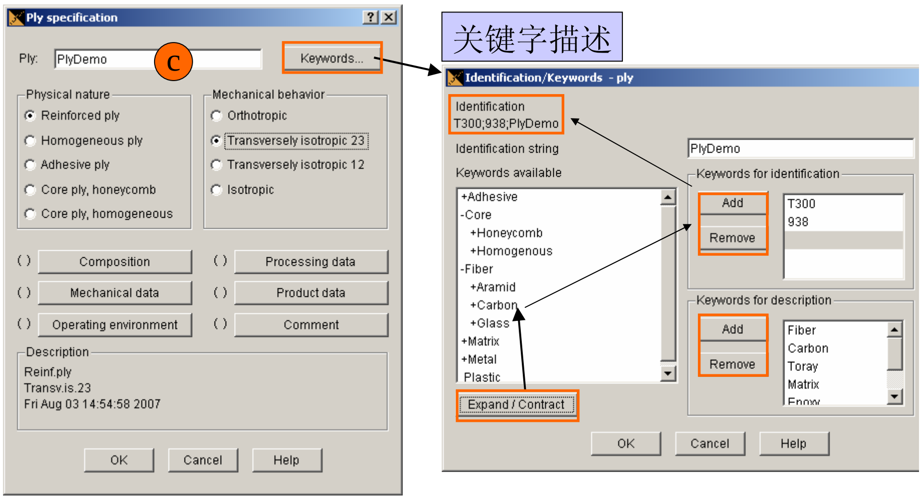
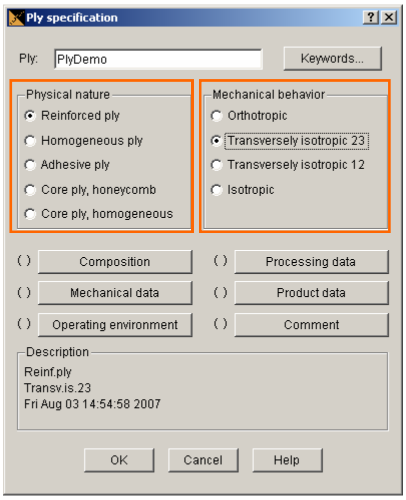
Specify a Ply

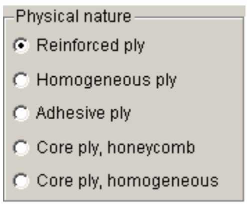


Specify a Ply 材料类型

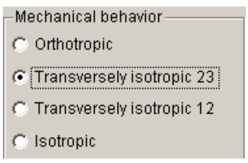
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Specify a Ply





- 增强层
- 均质层，各向同性层
- 粘胶层
- 夹芯层，蜂窝材料
- 夹芯层，均质材料



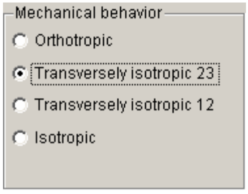
- 正交各向异性
- 23面内横观各向同性
- 12面内横观各向同性
- 各向同性

- 五种材料类型和四种力学本构关系可以任意组合（粘胶材料例外，只能定义为各向同性材料）

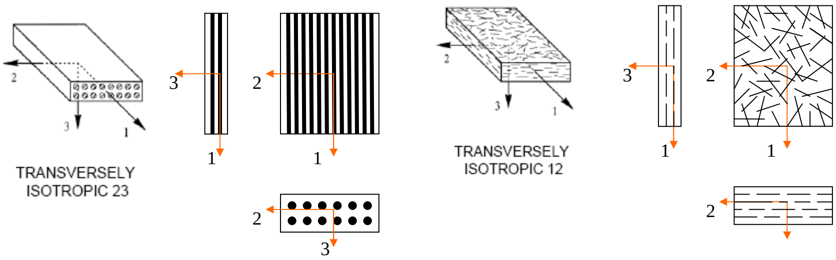
Specify a Ply 材料类型

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Specify a Ply



- 正交各向异性
- 23面内横观各向同性
- 12面内横观各向同性
- 各向同性



Specify a Ply 输入数据

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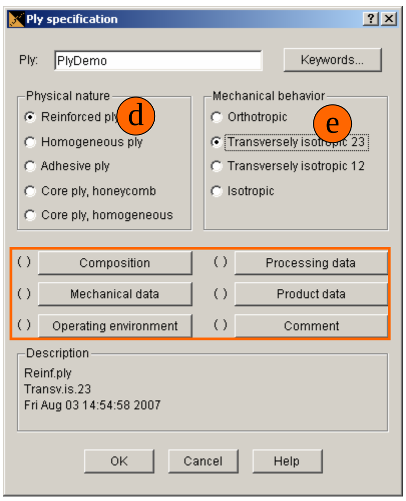
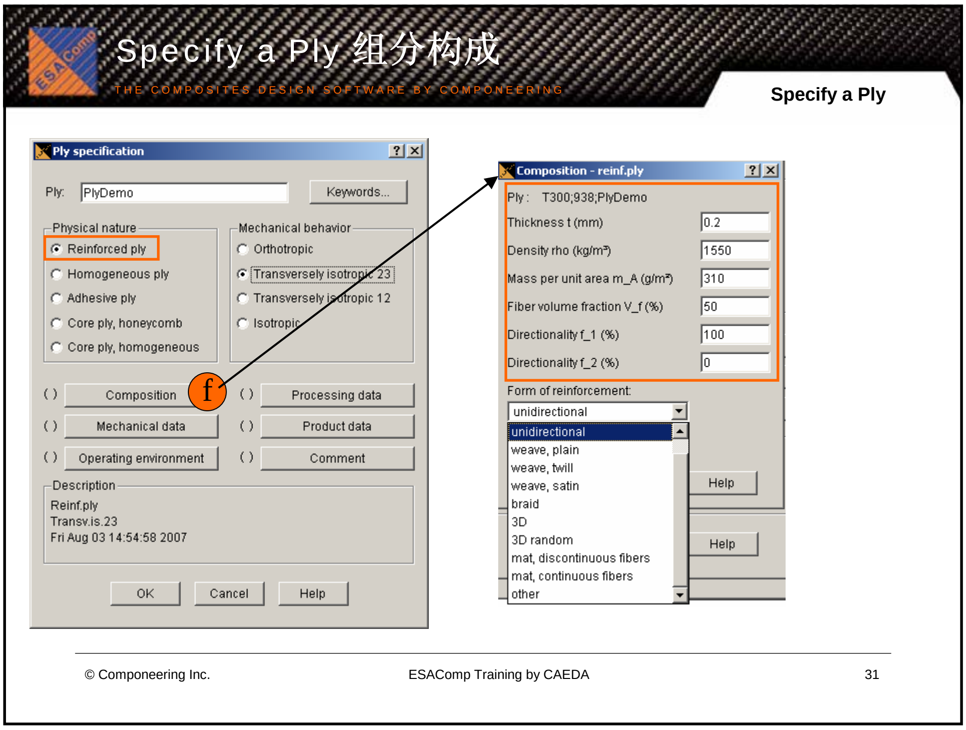
Specify a Ply



- 组分构成
- 力学性能
- 使用环境
- 工艺数据
- 产品数据
- 评述备注


Specify a Ply 组分构成
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Specify a Ply
Ply specification
Ply: PlyDemo
Keywords...
Physical nature
Reinforced ply
Homogeneous ply
Adhesive ply
Core ply, honeycomb
Core ply, homogeneous
Mechanical behavior
Orthotropic
Transversely isotropic 23
Transversely isotropic 12
Isotropic
f
Composition
Processing data
Mechanical data
Product data
Operating environment
Comment
Description
Reinf.ply
Transv.is.23
Fri Aug 03 14:54:58 2007
OK
Cancel
Help
Composition - reinf.ply
Ply : T300;938;PlyDemo
Thickness t (mm) 0.2
Density rho (kg/m³) 1550
Mass per unit area m_A (g/m²) 310
Fiber volume fraction V_f (%) 50
Directionality f_1 (%) 100
Directionality f_2 (%) 0
Form of reinforcement:
unidirectional
unidirectional
weave, plain
weave, twill
weave, satin
braid
3D
3D random
mat, discontinuous fibers
mat, continuous fibers
other
Help
Help
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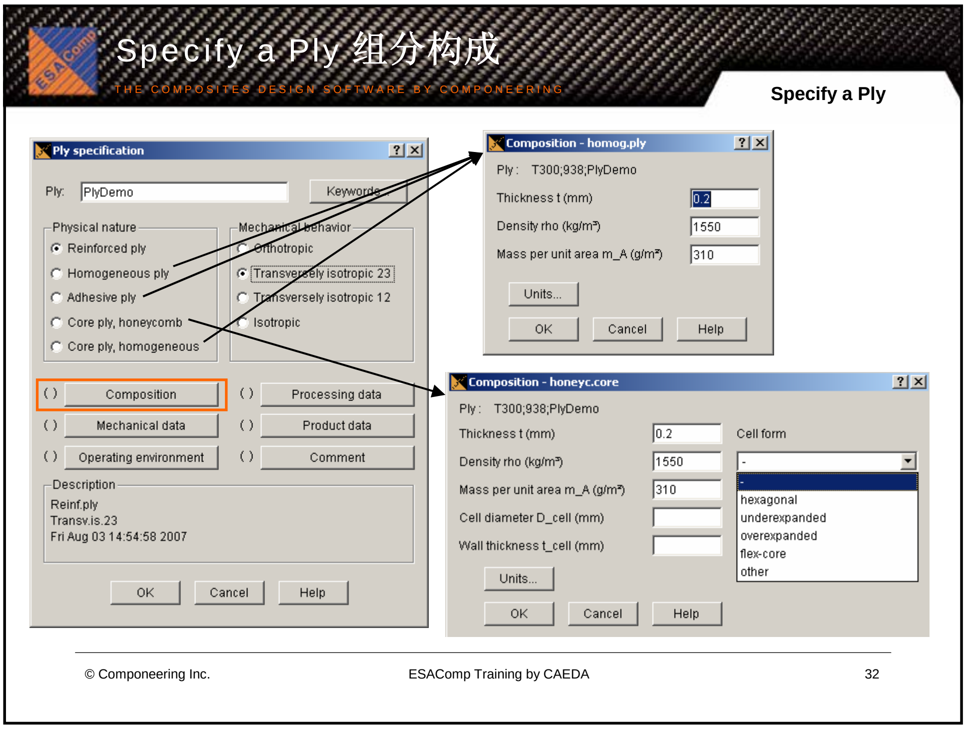
Specify a Ply 组分构成
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Specify a Ply
Ply specification
Ply: PlyDemo
Keywords
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Orthotropic
Transversely isotropic 23
Transversely isotropic 12
Isotropic
Composition
Processing data
Mechanical data
Product data
Operating environment
Comment
Description
Reinf.ply
Transv.is.23
Fri Aug 03 14:54:58 2007
OK
Cancel
Help
Composition - homog.ply
Ply : T300;938;PlyDemo
Thickness t (mm) 0.2
Density rho (kg/m³) 1550
Mass per unit area m_A (g/m²) 310
Units...
OK
Cancel
Help
Composition - honeyc.core
Ply : T300;938;PlyDemo
Thickness t (mm) 0.2
Cell form
Density rho (kg/m³) 1550
Mass per unit area m_A (g/m²) 310
Cell diameter D_cell (mm)
Wall thickness t_cell (mm)
hexagonal
underexpanded
overexpanded
flex-core
other
Units...
OK
Cancel
Help
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Specify a Ply 力学性能

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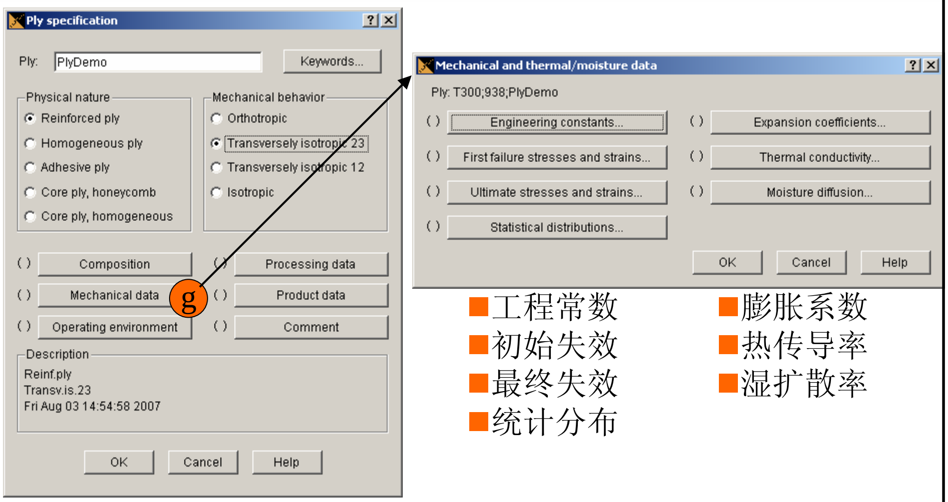
Specify a Ply

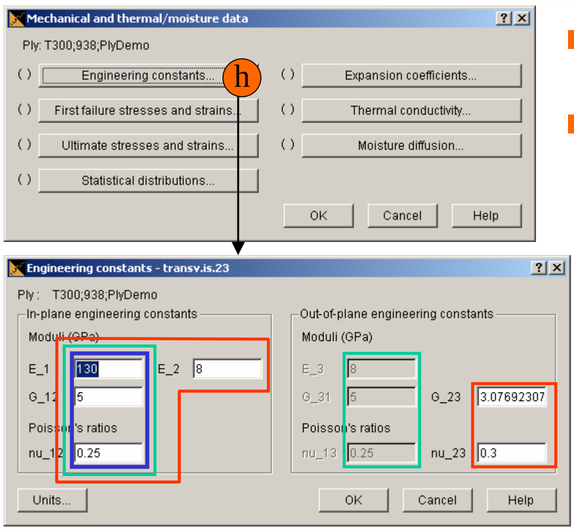


- 工程常数
- 初始失效
- 最终失效
- 统计分布
- 膨胀系数
- 热传导率
- 湿扩散率

Specify a Ply 工程常数

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Specify a Ply



- 需要输入的常数个数由其力学属性确定
- 相关参数必须满足一定的限制条件

ISOTROPIC
T-ISO12
T-ISO23
ORTHOTROPIC(all)

Specify a Ply 工程常数

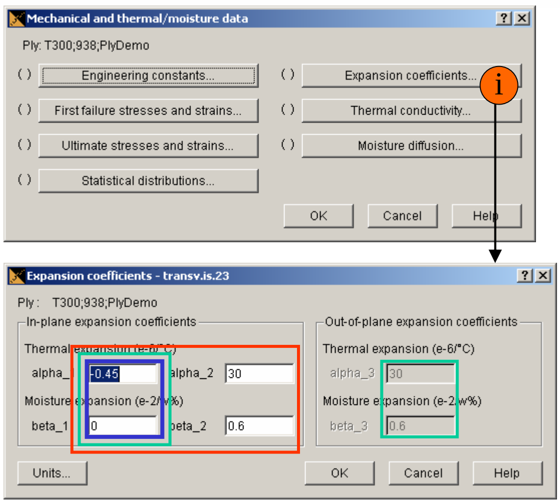
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

- 相关参数必须满足一定的限制条件：
- **ISOTROPIC**：$G = \dfrac{E}{2(1+\upsilon)}$ **T-ISO23**：$G_{23} = \dfrac{E_3}{2(1+\upsilon_{23})}$

  T-ISO12：$G_{12} = \dfrac{E_1}{2(1+\upsilon_{12})}$
- $\dfrac{E_i}{\upsilon_{ij}} = \dfrac{E_j}{\upsilon_{ji}}$ ，故无须填写 υ_{ji}
- $\upsilon_{ij}^2 < \dfrac{E_i}{E_j}$

Specify a Ply 膨胀系数

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING



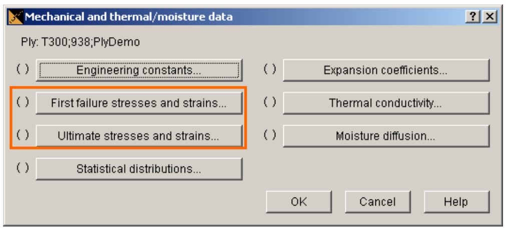
ISOTROPIC T-ISO12 T-ISO23 ORTHOTROPIC(all)

- 需要输入的常数个数由其力学属性确定

$$\{\varepsilon_0^{\Delta T}\}_{123} = \Delta T\{\alpha\}_{123}$$

$$\{\varepsilon_0^{\Delta m}\}_{123} = \Delta m\{\beta\}_{123}$$

$$\{\alpha\}_{123} = \begin{Bmatrix}\alpha_1\\ \alpha_2\\ \alpha_3\\ 0\\ 0\\ 0\end{Bmatrix} \qquad \{\beta\}_{123} = \begin{Bmatrix}\beta_1\\ \beta_2\\ \beta_3\\ 0\\ 0\\ 0\end{Bmatrix}$$



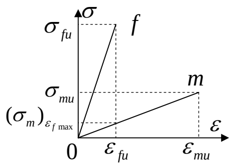
- 由混合(并联)模型得到复合材料的应力：

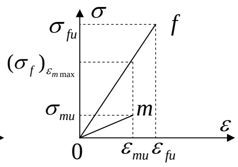
$$\sigma_c = \sigma_f V_f + \sigma_m (1-V_f)$$

- 当纤维与基体具有相同的拉伸破坏应变时，即纤维与基体同时破坏，初始失效=最终失效，$\sigma_{cu} = \sigma_{fu} V_f + \sigma_{mu}(1-V_f)$
- 当纤维与基体的拉伸破坏应变不同时，分两种情况：

<u>脆性纤维增强韧性基体</u>

<u>韧性纤维增强脆性基体</u>

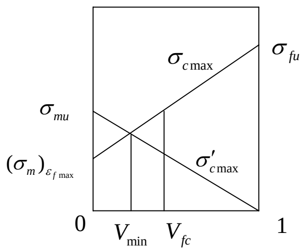




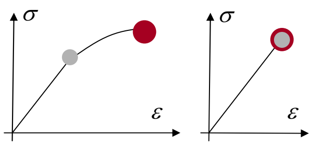
<u>脆性纤维增强韧性基体</u>

纤维的破坏应变 $\varepsilon_{f\max}$ 比基体的小，当复合材料应变达到 $\varepsilon_{f\max}$ 时纤维首先断裂，失效应力为 $\sigma_{c\max} = \sigma_{fu} V_f + (\sigma_m)_{\varepsilon_{f\max}} (1-V_f)$ ，纤维破坏后基体承担所有载荷，极限应力 $\sigma'_{c\max} = \sigma_{mu}(1-V_f)$ 。为使复合材料的强度不小于基体强度，要求 $V_f \geq V_{fc}$。

- 当 $V_f < V_{\min}$ 时，在基体破坏前，纤维会多级破坏，初始失效<最终失效；
- 当 $V_f \geq V_{\min}$ 时，纤维断裂则整体破坏，初始失效=最终失效。



$$V_{fc} = \frac{\sigma_{mu} - (\sigma_m)_{\varepsilon_{f\max}}}{\sigma_{fu} - (\sigma_m)_{\varepsilon_{f\max}}}$$



Specify a Ply 初始与最终失效

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

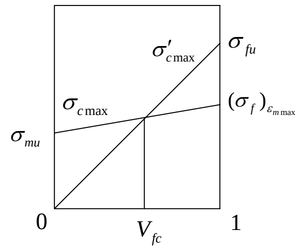
Specify a Ply

■韧性纤维增强脆性基体

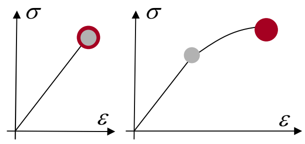
纤维的破坏应变 $\varepsilon_{m\max}$ 比基体的高，当应变达到 $\varepsilon_{m\max}$ 时基体首先破坏。

•当 $V_f < V_{fc}$ 时，纤维与基体一起整体破坏，极限应力为 $\sigma_{c\max} = (\sigma_f)_{\varepsilon_{m\max}} V_f + \sigma_{mu}(1-V_f)$ ，初始失效=最终失效；

•当 $V_f \ge V_{fc}$ 时，基体破坏后由纤维承担所有载荷，基体发生多级断裂，极限应力为 $\sigma'_{c\max} = \sigma_{fu} V_f$ ，初始失效<最终失效。



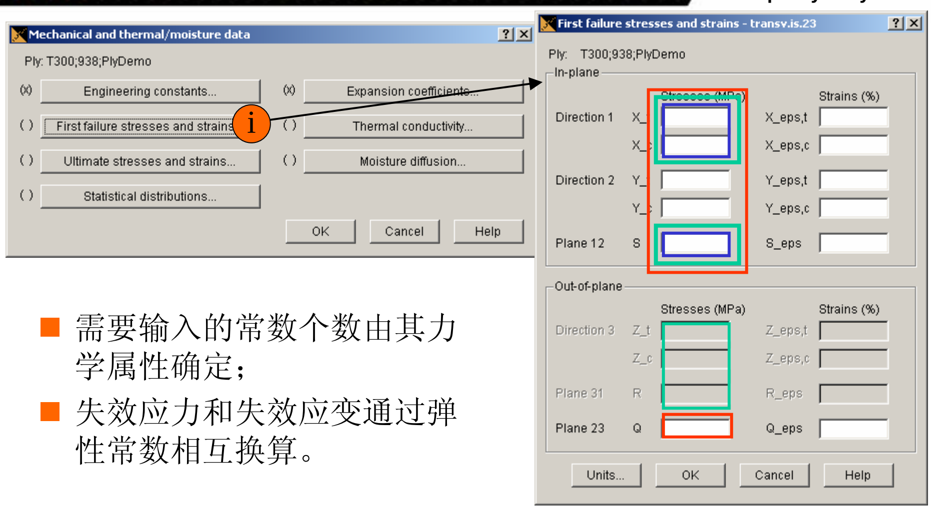
$$V_{fc} = \frac{\sigma_{mu}}{\sigma_{fu} + \sigma_{mu} - (\sigma_f)_{\varepsilon_{m\max}}}$$



Specify a Ply 初始失效

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Specify a Ply



■ 需要输入的常数个数由其力学属性确定；

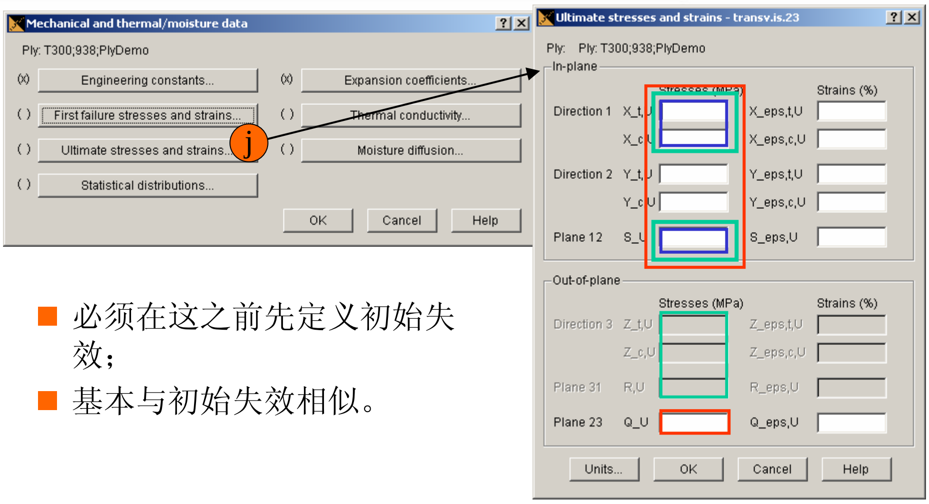
■ 失效应力和失效应变通过弹性常数相互换算。

ISOTROPIC T-ISO12 T-ISO23 ORTHOTROPIC(all)

Specify a Ply 最终失效

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Specify a Ply



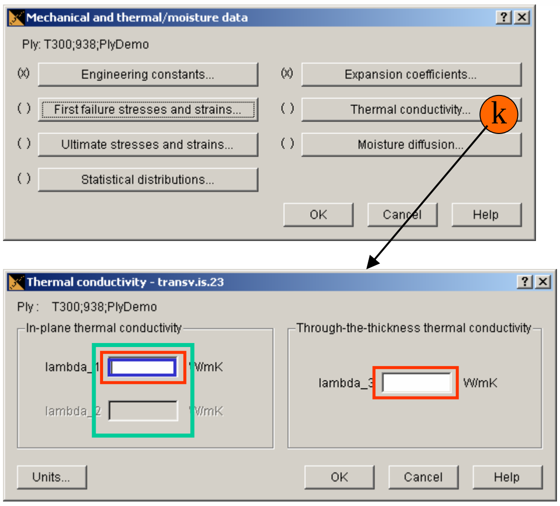
- 必须在这之前先定义初始失效；
- 基本与初始失效相似。

ISOTROPIC T-ISO12 T-ISO23 ORTHOTROPIC(all)

Specify a Ply 热传导率

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Specify a Ply



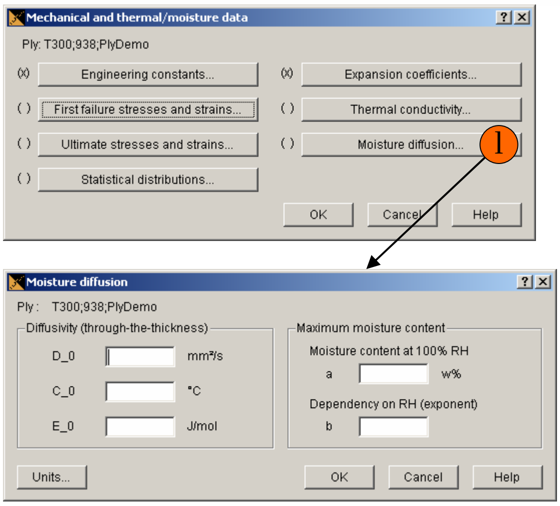
- 需要输入的常数个数由其力学属性确定；
- 分别是三个方向的热传导率。

ISOTROPIC
T-ISO12
T-ISO23
ORTHOTROPIC(all)

Specify a Ply 湿扩散率

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Specify a Ply

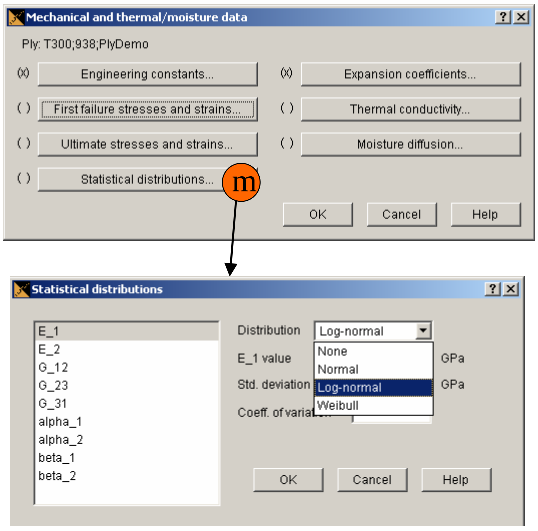


- 扩散系数(沿厚度方向)
- 最大的吸湿率。

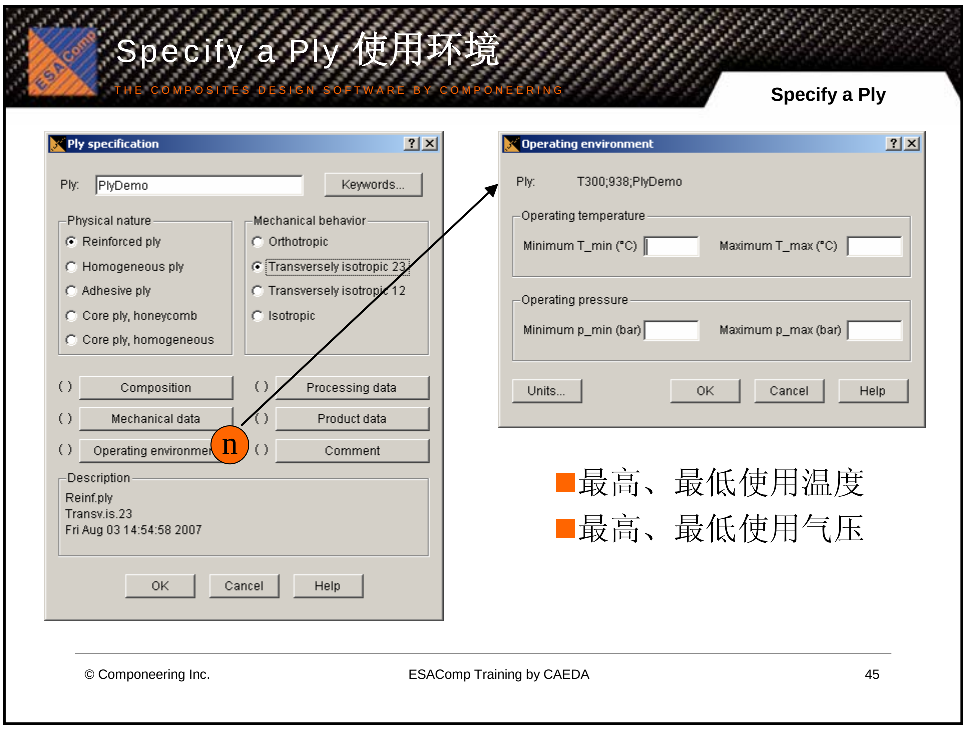
Specify a Ply 统计分布

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Specify a Ply



- 只有弹性常数和膨胀系数的分散性分析，不包括强度、传导率等指标；
- 三种分布规律：正态分布、对数正态分布、韦布尔分布；
- 两个参量：标准差、方差。



Specify a Ply 使用环境
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Specify a Ply
Ply specification
Ply: PlyDemo
Keywords...
Physical nature
Reinforced ply
Homogeneous ply
Adhesive ply
Core ply, honeycomb
Core ply, homogeneous
Mechanical behavior
Orthotropic
Transversely isotropic 23
Transversely isotropic 12
Isotropic
Composition
Mechanical data
Operating environment
Processing data
Product data
Comment
Description
Reinf.ply
Transv.is.23
Fri Aug 03 14:54:58 2007
OK
Cancel
Help
Operating environment
Ply: T300;938;PlyDemo
Operating temperature
Minimum T_min (°C)
Maximum T_max (°C)
Operating pressure
Minimum p_min (bar)
Maximum p_max (bar)
Units...
OK
Cancel
Help
最高、最低使用温度
最高、最低使用气压
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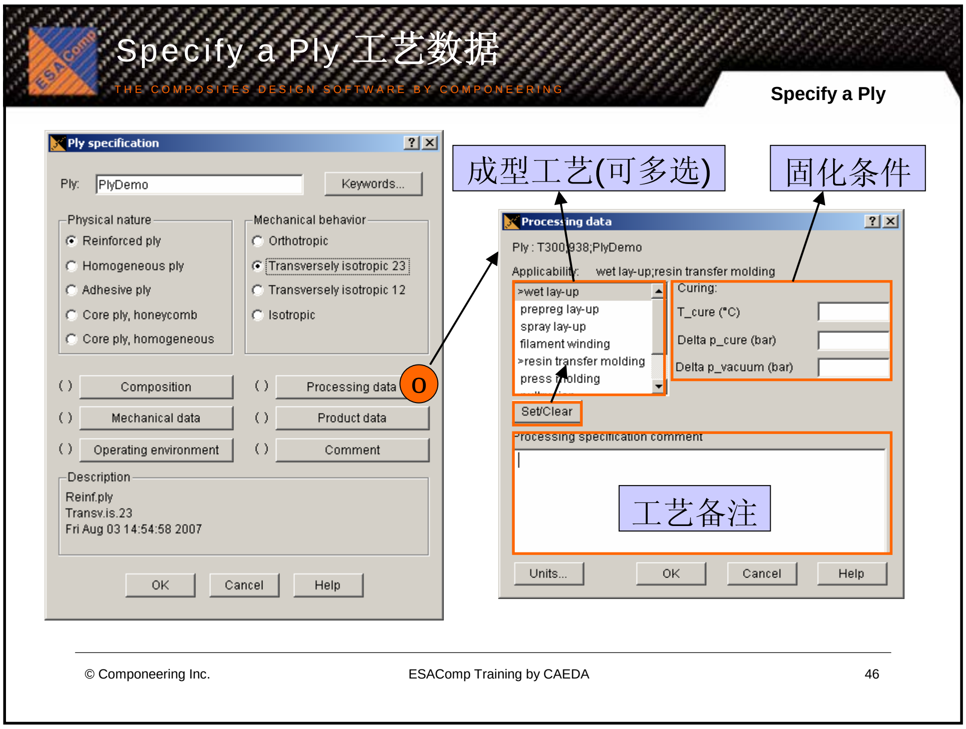

Specify a Ply 工艺数据
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Specify a Ply
Ply specification
Ply: PlyDemo
Keywords...
Physical nature
Reinforced ply
Homogeneous ply
Adhesive ply
Core ply, honeycomb
Core ply, homogeneous
Mechanical behavior
Orthotropic
Transversely isotropic 23
Transversely isotropic 12
Isotropic
Composition
Mechanical data
Operating environment
Processing data
Product data
Comment
Description
Reinf.ply
Transv.is.23
Fri Aug 03 14:54:58 2007
OK
Cancel
Help
成型工艺(可多选)
固化条件
Processing data
Ply : T300;938;PlyDemo
Applicability: wet lay-up;resin transfer molding
>wet lay-up
prepreg lay-up
spray lay-up
filament winding
>resin transfer molding
press molding
Curing:
T_cure (°C)
Delta p_cure (bar)
Delta p_vacuum (bar)
Set/Clear
Processing specification comment
工艺备注
Units...
OK
Cancel
Help
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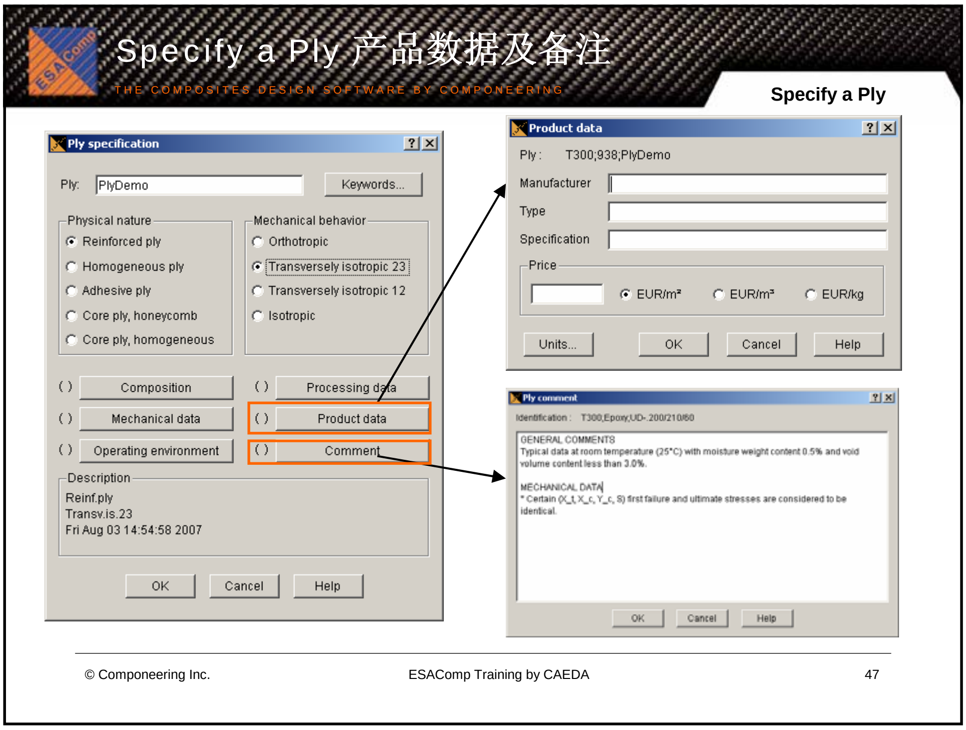
Specify a Ply 产品数据及备注
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Specify a Ply
Ply specification
Ply: PlyDemo
Keywords...
Physical nature
Reinforced ply
Homogeneous ply
Adhesive ply
Core ply, honeycomb
Core ply, homogeneous
Mechanical behavior
Orthotropic
Transversely isotropic 23
Transversely isotropic 12
Isotropic
Composition
Mechanical data
Operating environment
Processing data
Product data
Comment
Description
Reinf.ply
Transv.is.23
Fri Aug 03 14:54:58 2007
OK
Cancel
Help
Product data
Ply: T300;938;PlyDemo
Manufacturer
Type
Specification
Price
EUR/m²
EUR/m³
EUR/kg
Units...
Ply comment
Identification: T300,Epoxy,UD- 200/210/60
GENERAL COMMENTS
Typical data at room temperature (25°C) with moisture weight content 0.5% and void volume content less than 3.0%.
MECHANICAL DATA
* Certain (X_t, X_c, Y_c, S) first failure and ultimate stresses are considered to be identical.
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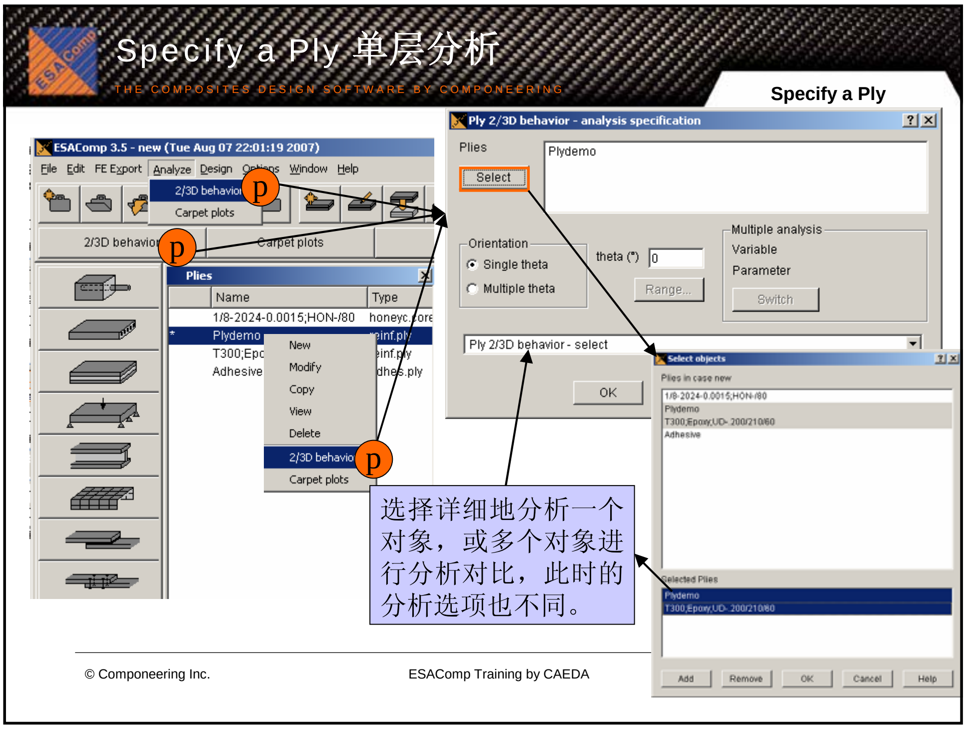
Specify a Ply 单层分析
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Specify a Ply
ESAComp 3.5 - new (Tue Aug 07 22:01:19 2007)
File Edit FE Export Analyze Design Options Window Help
2/3D behavior
Carpet plots
Plies
Name
Type
1/8-2024-0.0015;HON-/80
honeyc.core
Plydemo
T300;Epo
Adhesive
New
Modify
Copy
View
Delete
Ply 2/3D behavior - analysis specification
Select
Orientation
Single theta
Multiple theta
theta (°)
Range...
Multiple analysis
Variable
Parameter
Switch
Ply 2/3D behavior - select
OK
Select objects
Plies in case new
Selected Plies
Add
Remove
Cancel
Help
选择详细地分析一个对象，或多个对象进行分析对比，此时的分析选项也不同。
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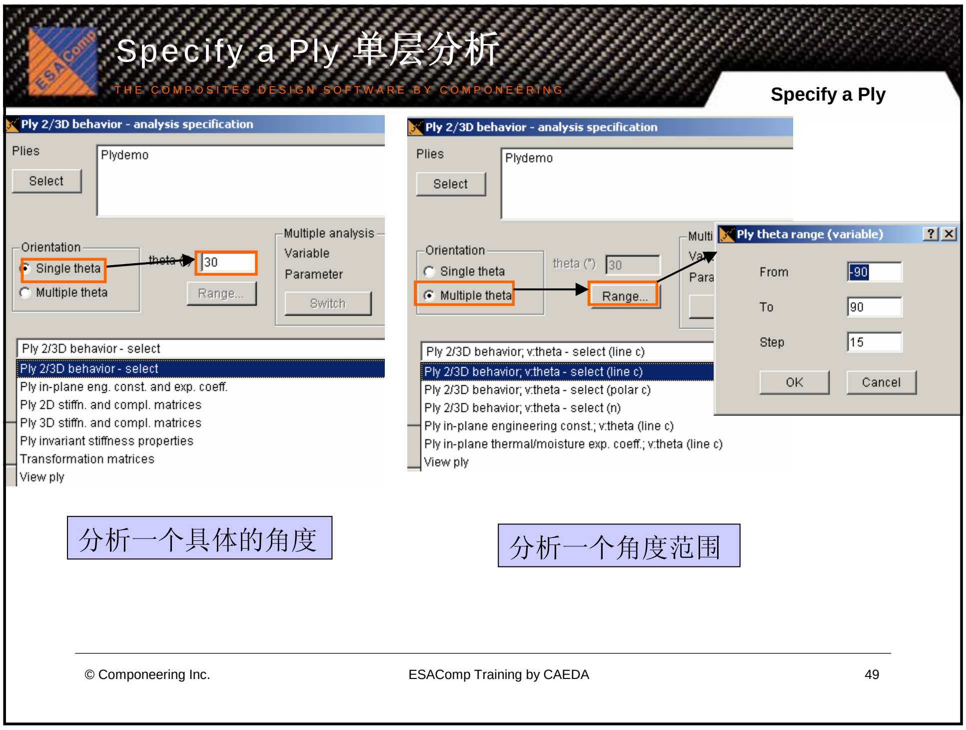
Specify a Ply 单层分析
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Specify a Ply
Ply 2/3D behavior - analysis specification
Plies
Select
Plydemo
Orientation
Single theta
Multiple theta
theta
30
Range...
Multiple analysis
Variable
Parameter
Switch
Ply 2/3D behavior - select
Ply 2/3D behavior - select
Ply in-plane eng. const. and exp. coeff.
Ply 2D stiffn. and compl. matrices
Ply 3D stiffn. and compl. matrices
Ply invariant stiffness properties
Transformation matrices
View ply
Ply theta range (variable)
From
-90
To
90
Step
15
OK
Cancel
Ply 2/3D behavior; v:theta - select (line c)
Ply 2/3D behavior; v:theta - select (line c)
Ply 2/3D behavior; v:theta - select (polar c)
Ply 2/3D behavior; v:theta - select (n)
Ply in-plane engineering const.; v:theta (line c)
Ply in-plane thermal/moisture exp. coeff.; v:theta (line c)
View ply
分析一个具体的角度
分析一个角度范围
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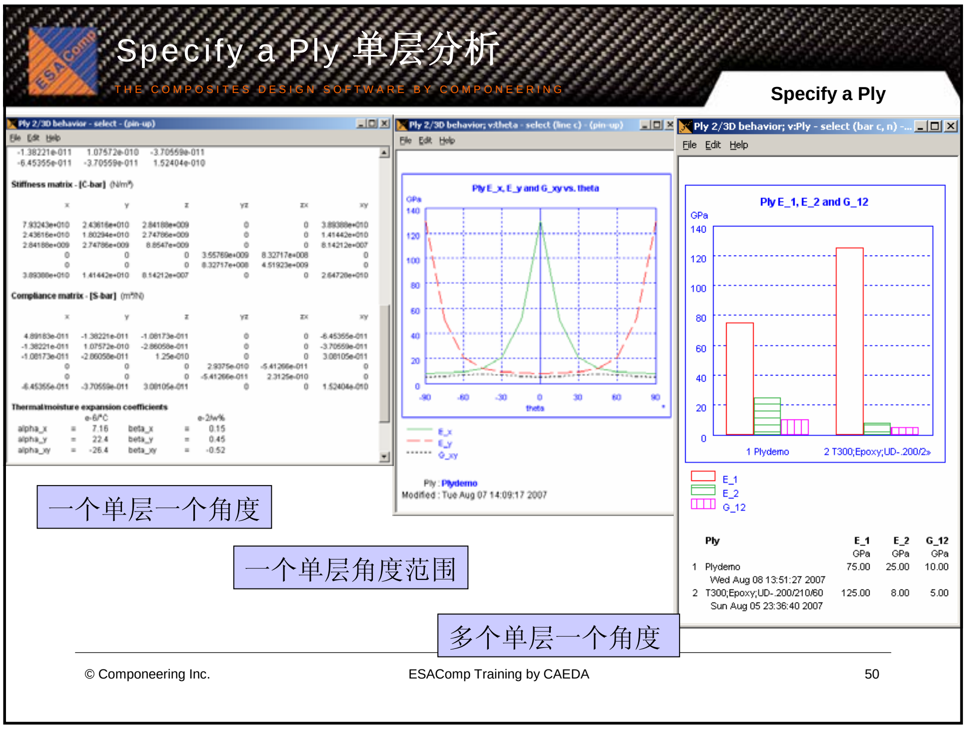
Specify a Ply 单层分析
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Specify a Ply
Ply 2/3D behavior - select - (pin-up)
Stiffness matrix - [C-bar]
Compliance matrix - [S-bar]
Thermal/moisture expansion coefficients
Ply 2/3D behavior; v:theta - select (line c) - (pin-up)
Ply E_x, E_y and G_xy vs. theta
GPa
theta
E_x
E_y
G_xy
Ply : Plydemo
Modified : Tue Aug 07 14:09:17 2007
Ply 2/3D behavior; v:Ply - select (bar c, n)
Ply E_1, E_2 and G_12
GPa
1 Plydemo
2 T300;Epoxy;UD-200/2»
E_1
E_2
G_12
Ply
1 Plydemo Wed Aug 08 13:51:27 2007 75.00 25.00 10.00
2 T300;Epoxy;UD-200/210/60 Sun Aug 05 23:36:40 2007 125.00 8.00 5.00
一个单层一个角度
一个单层角度范围
多个单层一个角度
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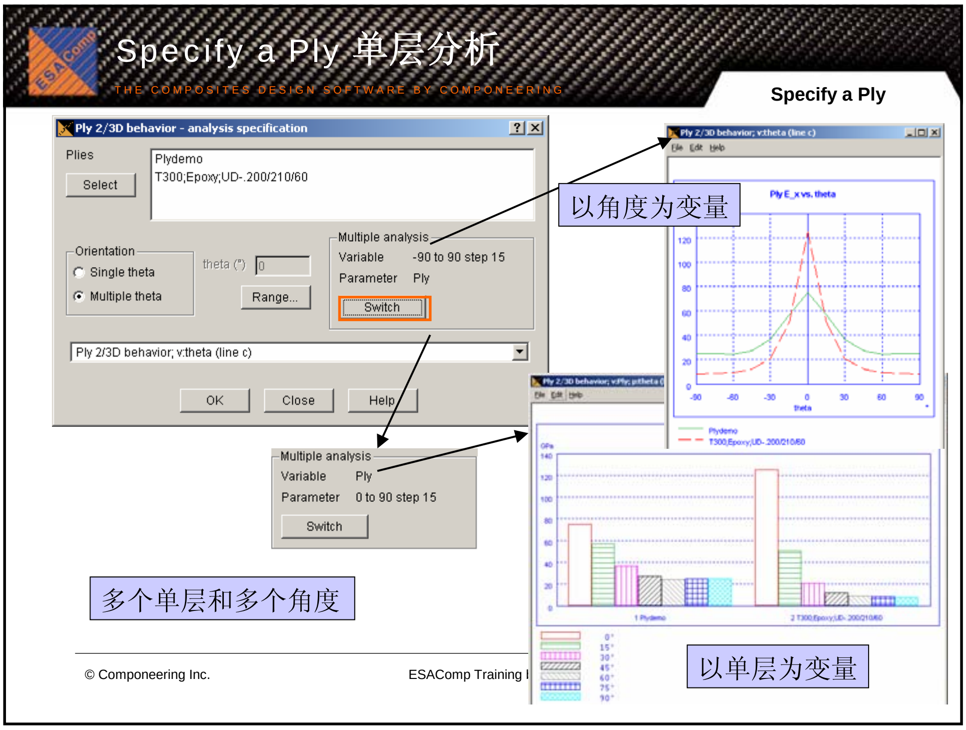
Specify a Ply 单层分析
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Specify a Ply
Ply 2/3D behavior - analysis specification
Plies
Plydemo
T300;Epoxy;UD-.200/210/60
Select
Orientation
Single theta
Multiple theta
theta (°)
Range...
Multiple analysis
Variable -90 to 90 step 15
Parameter Ply
Switch
Ply 2/3D behavior; v:theta (line c)
OK
Close
Help
Multiple analysis
Variable Ply
Parameter 0 to 90 step 15
Switch
以角度为变量
多个单层和多个角度
以单层为变量
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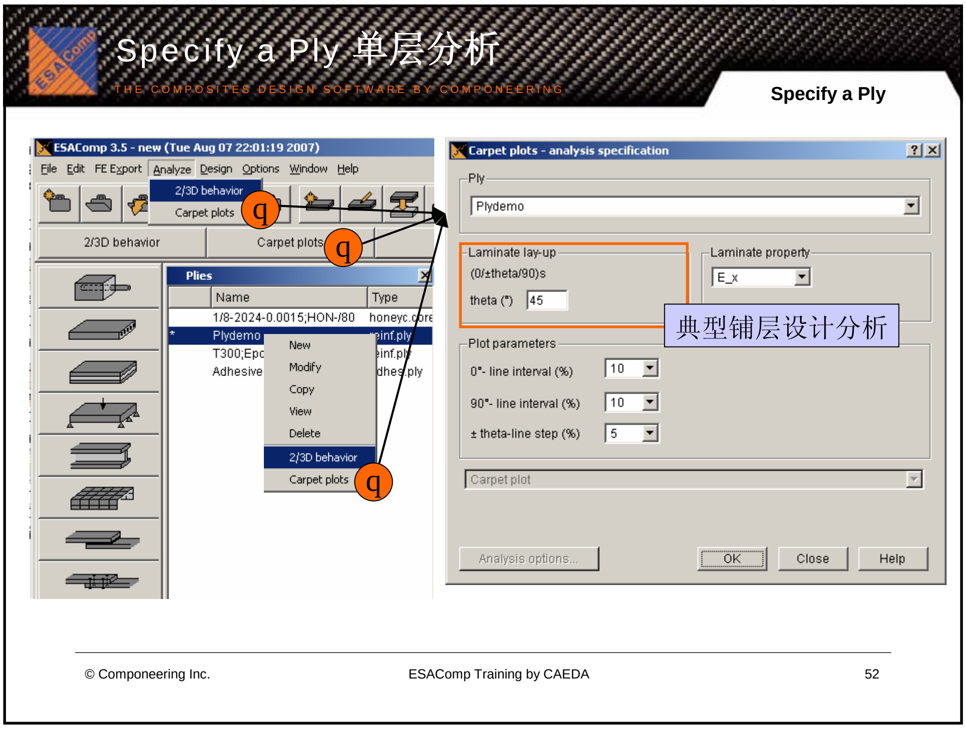
ESAComp Training


Specify a Ply 单层分析
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Specify a Ply
ESAComp 3.5 - new (Tue Aug 07 22:01:19 2007)
File Edit FE Export Analyze Design Options Window Help
2/3D behavior
Carpet plots
Plies
Name
Type
1/8-2024-0.0015;HON-/80
Plydemo
New
Modify
Copy
View
Delete
Carpet plots - analysis specification
Ply
Plydemo
Laminate lay-up
(0/±theta/90)s
theta (°) 45
Laminate property
E_x
典型铺层设计分析
Plot parameters
0°- line interval (%) 10
90°- line interval (%) 10
± theta-line step (%) 5
Carpet plot
Analysis options...
OK
Close
Help
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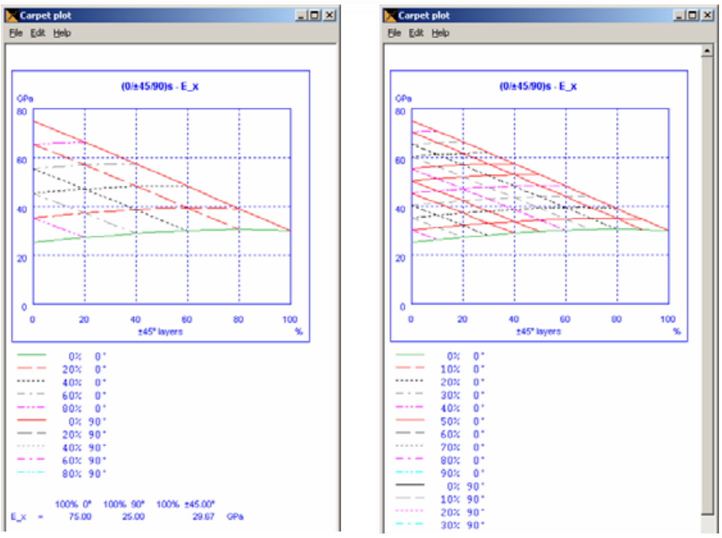
Specify a Ply 单层分析

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Specify a Ply



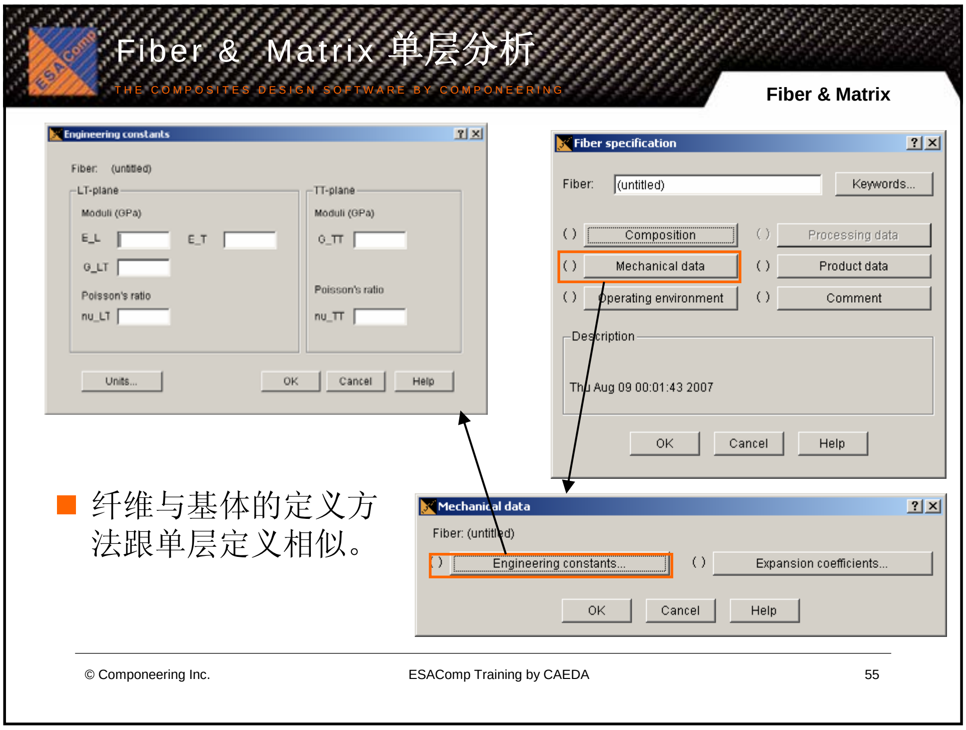
Specify a Ply 练习

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

Specify a Ply

- Create two reinforced plies with transv. iso 23 as material behavior, one core ply with isotropic behavior and one adhesive ply.

UD_1	UD_2	Core_3	adhesive_1
Thickness: 0.3mm	Thickness: 0.3mm	Density: 77 kg/m3	Thickness: 0.3mm
Density: 1600 kg/m3	Density: 1850 kg/m3	Ex=70 MPa	Density: 1600 kg/m3
Ex=115000 MPa	Ex=38000 MPa	Gxy=24 MPa	Ex=1400 MPa
Ey=6500 MPa	Ey=9000 MPa	X_t=1.6 MPa	Gxy=500 MPa
Gxy=6000 MPa	Gxy=4500 MPa	X_c=1 MPa	X_t=25 MPa
Nuxy=0.28	Nuxy=0.30	S=0.9 MPa	X_c=40 MPa
Nuyz=0.34	Nuyz=0.30		S=25 MPa
X_t=2200 MPa	X_t=930 MPa		X_t,u=27 MPa
X_c=810 MPa	X_c=570 MPa		X_c,u=44 MPa
Y_t=40 MPa	Y_t=35 MPa		S,u=27 MPa
Y_c=190 MPa	Y_c=110 MPa		X_eps,t,u=8.9
S=50 MPa	S=70 MPa		X_eps,c,u=14.25
Q=50 MPa	Q=70 MPa		S_eps,u=25


Fiber & Matrix 单层分析
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Fiber & Matrix
Engineering constants
Fiber: (untitled)
LT-plane
Moduli (GPa)
E_L
E_T
G_LT
Poisson's ratio
nu_LT
TT-plane
Moduli (GPa)
G_TT
Poisson's ratio
nu_TT
Units...
OK
Cancel
Help
Fiber specification
Fiber:
(untitled)
Keywords...
Composition
Processing data
Mechanical data
Product data
Operating environment
Comment
Description
Thu Aug 09 00:01:43 2007
OK
Cancel
Help
■ 纤维与基体的定义方法跟单层定义相似。
Mechanical data
Fiber: (untitled)
Engineering constants...
Expansion coefficients...
OK
Cancel
Help
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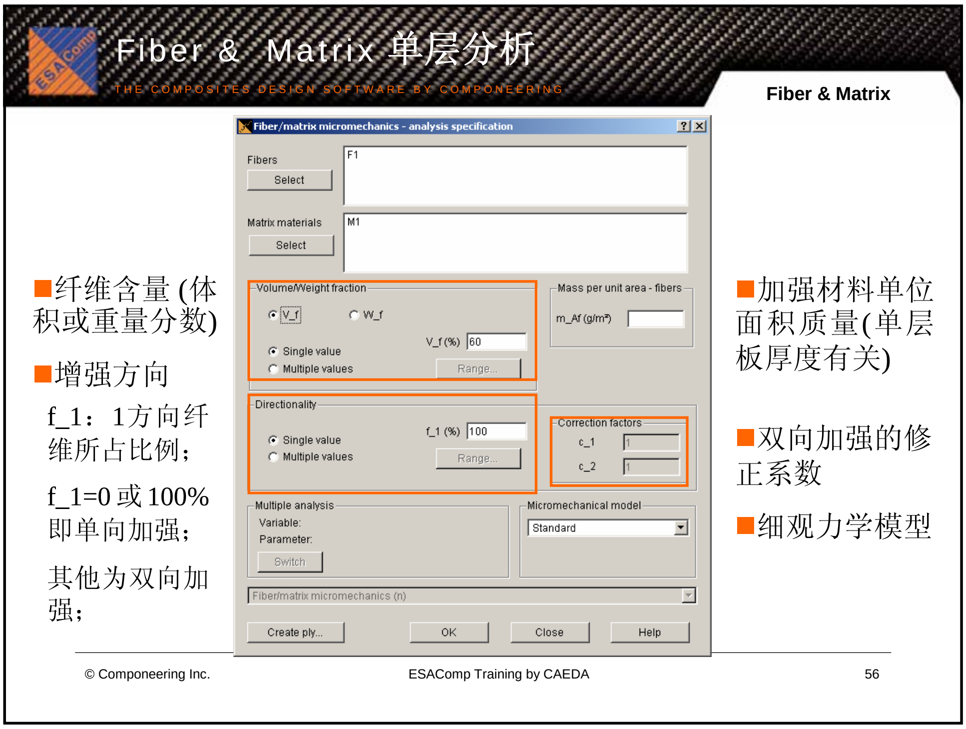
Fiber & Matrix 单层分析
THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING
Fiber & Matrix
Fiber/matrix micromechanics - analysis specification
Fibers
Select
F1
Matrix materials
Select
M1
Volume/Weight fraction
V_f
W_f
Single value
Multiple values
V_f (%)
60
Range...
Mass per unit area - fibers
m_Af (g/m²)
Directionality
Single value
Multiple values
f_1 (%)
100
Range...
Correction factors
c_1
1
c_2
1
Multiple analysis
Variable:
Parameter:
Switch
Micromechanical model
Standard
Fiber/matrix micromechanics (n)
Create ply...
OK
Close
Help
■纤维含量 (体积或重量分数)
■增强方向
f_1：1方向纤维所占比例；
f_1=0 或 100% 即单向加强；
其他为双向加强；
■加强材料单位面积质量(单层板厚度有关)
■双向加强的修正系数
■细观力学模型
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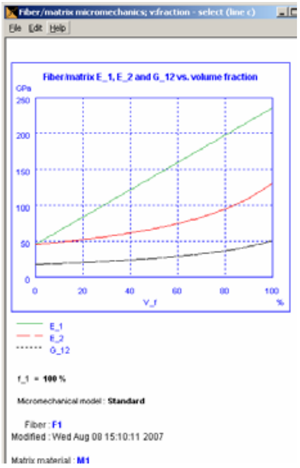
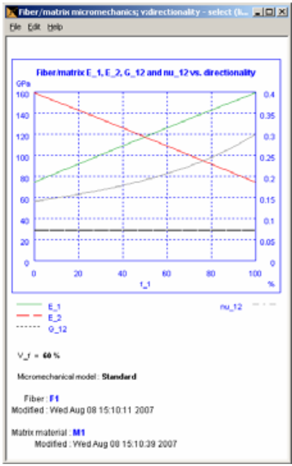
Fiber & Matrix 单层分析

- 双向加强的性能数据根据单向板和层压板理论计算。
- 可以根据细观力学分析结果辅助设计单层板。
- 单层板对象与纤维\基体对象目前没有直接关联，关键字只起到描述注释作用。





练习

- 导入纤维和基体材料
- 创建纤维和基体材料
- 对纤维和基体组合进行细观力学分析

ESAComp Training

罗炜桓
Technical Consultant
CAEDA 技术支持中心

The software by Componeering
CAEDA

www.caeda.com.cn ; rimbaur@126.com

Laminates 术语

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

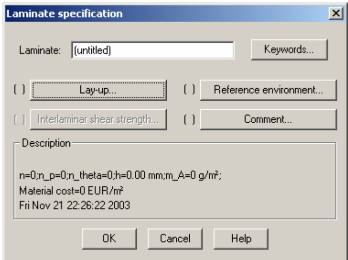
LAMINATES SPECIFICATION

- Ply vs. layer
  - ply = 材料 (ESAComp object)
  - layer = 层压板的铺层
  - n = 层压板的层数
  - n_p = 层压板所选用的单层材料种数
- 夹芯板看作是一种特殊的层压板
  - 系统自动识别夹芯层压板，并执行相应的分析算法
  - ”mixed” = laminate that is not solid or sandwich

Laminate specification top level

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

- 层压板铺层定义
- 层间剪切强度 (只有在定义好铺层才能够定义此项)
- 定义层压板的使用环境 (不会引起层压板应力显著变化的温度和湿度环境——stress-free environment)



Theta- and p-laminates

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

- 标准层压板: 每一个铺层都由其材料、厚度和铺层方向定义.
- 层压板参数分析
  - Theta-laminate: 将一个或者多个铺层的铺设角度定义为变量 theta. 用于分析随着theta 角度的变化层压板的性能的变化.
  - P-laminate:将一个或者多个铺层的厚度比例设为变量进行分析.

单层板选择

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- Selection of plies to be used in laminate lay-up construction

铺层定义窗口

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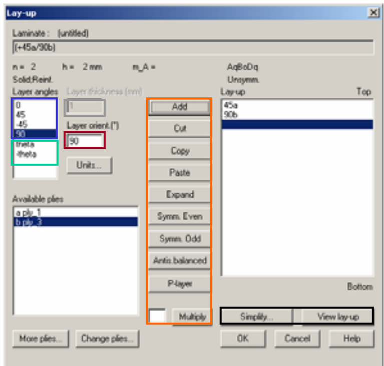
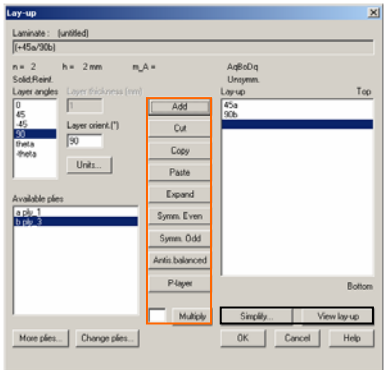
- □定义各个铺层标准方向
- □定制铺层方向
- □定义 theta-laminate 铺层方向
- □定制铺层厚度，在单层(ply)没有定义厚度的情况下
- □可以对一个或多个铺层进行对称等的操作
- □对整个层压板的显示、对称等操作

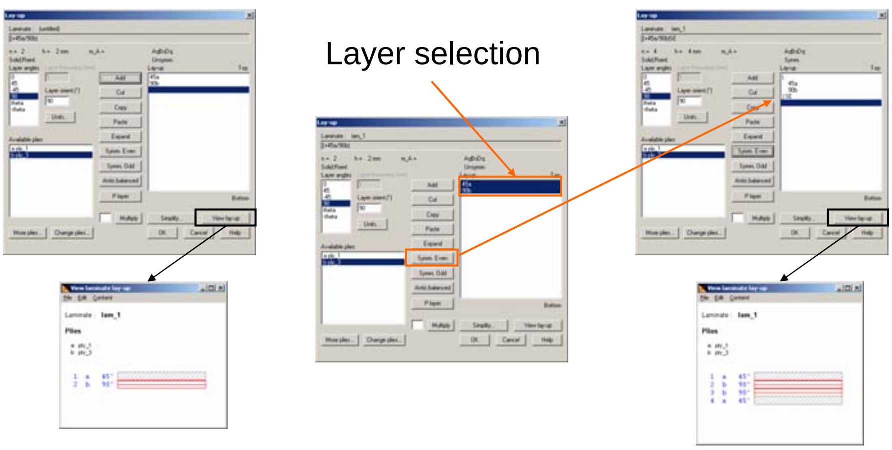


铺层操作

- Add, Cut, Copy, Paste: to add, cut or delete, copy, paste the selected layer
- Symm. Even, Symm. Odd, Antis.balanced, Multiply: to apply the specific operation on the selected layer or layers
- Expand: 将简写的铺层形式展开
- P-layer: 定义 p-laminate的P-layer:
- Simplify: 与Expand相反
- View lay-up: 图形化显示铺层



Symmetric even



Symmetric odd

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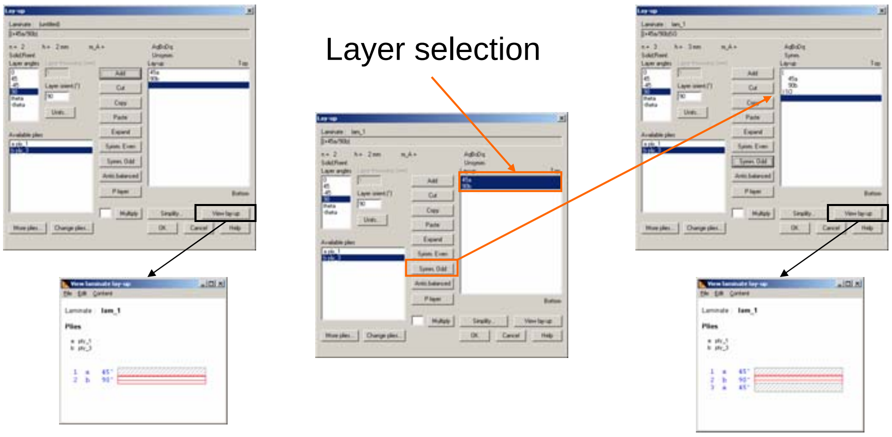
LAMINATES SPECIFICATION



Antisymmetric balanced

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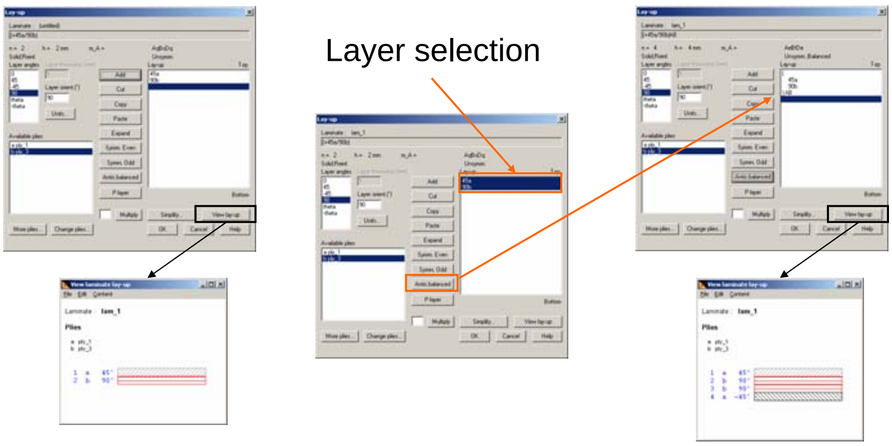
LAMINATES SPECIFICATION



Multiply

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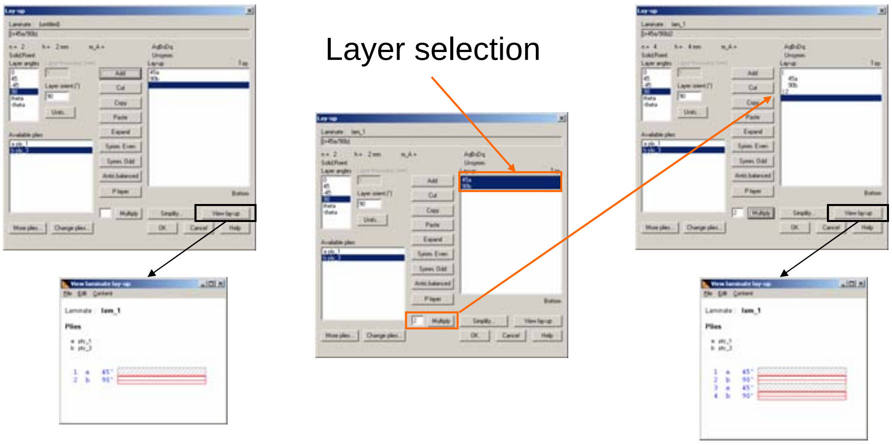

Simplify

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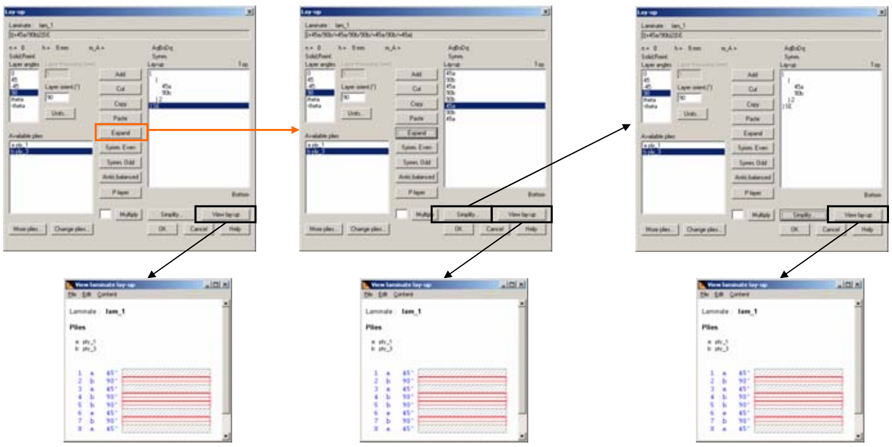

层间剪切强度

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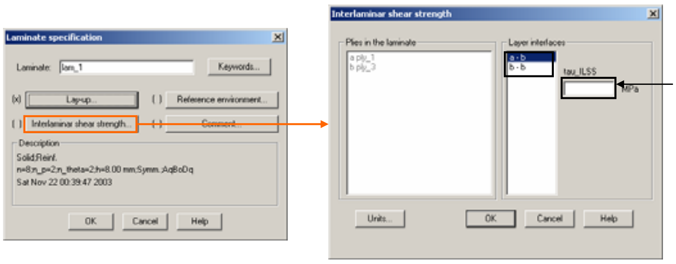
LAMINATES SPECIFICATION



Defined interlaminar shear strength for the selected layer interface

Interlaminar shear strength definition is now available

List of all ply interfaces in the laminate

Laminate lay-up specification

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PRACTICAL EXAMPLES

- Create 4 laminates with the same material:
  - One unsymmetric laminate: “general” [0° /30° /90°]
  - One antisymm. balanced laminate: “anti-balanced” $[30°]_{AB}$ = [30° /-30°]
  - One symmetric laminate: “symmetric” $[0°/30°]_{SE}$ = [0° /30° /30° /0°]
  - One symmetric balanced laminates: “symm. balanced” $[0°/30°/-30°]_{SE}$ = [0° /30° /-30° /-30° /30° /0°]
- Create a laminate load N_x = 100000 N/m

练习

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- 定义Theta-laminate：[0/ θ /- θ /90] $_{SE}$
- 定义P-laminate：[0/45P/- 45P/90] $_{SE}$
- 定义夹芯蜂窝板：[0/90/Core] $_{SO}$, Core20mm厚

Laminate Analyses

层压板分析范围

- 2.5D behavior
  - 基于经典层压板理论的刚度和湿热扩展分析，面内和弯曲分析。
  - 横向剪切刚度
- 载荷响应和破坏分析
  - 在给定的（多轴向）载荷作用下的层压板响应
- 强度分析
  - 单向加载下的层压板强度

横向剪应力分析

- ESAComp采用基于经典层压板理论（ Classical Lamination Theory ）和一阶剪切变形理论（ First Order Shear Deformation Theory ）的方法进行横向剪应力分析
- Shear stress distributions: Q_x , $Q_y \Rightarrow \tau_{zx}(z)$, $\tau_{yz}(z)$
  - load response and failure analyses
- 增强的横向剪切强度分析
  - plate analyses

Laminate failure analyses – 1

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- 单层初始破坏分析(First Ply Failure analysis ,FPF)
  - 基于所选的破坏准则和单层板初始破坏强度（线形应力应变曲线）
  - 可以采用考虑横向剪应力的三维破坏准则 (ESAComp 3.0: 用户自定义准则; 即将增添最新的Puck and Cuntze 准则)
  - 构成了各种结构单元 (plates, beams, mechanical joints,…)强度分析的基础

Laminate failure analyses – 2

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- 层压板破坏降阶分析(Degraded laminate failure ,DLF) 与初始破坏分析类似，不过采用最终破坏应力-应变曲线的正切模量
  - 假设层压板整体 降阶状态(基体裂纹已经扩展到邻近铺层)
  - 适用于各种分析: *Laminate failure*, *Strength*, *Envelopes*

- 夹芯板夹层剪切破坏分析
  - 只要存在横向剪力就进行计算 (-> 需要夹层的横向剪切强度数据)
  - 对于正交各项异性夹层

$$f_c = \max\left(\frac{|\tau_{23}|}{Q}, \frac{|\tau_{31}|}{R}\right)$$

  - 各向同性夹层

$$f_c = \frac{\tau_{23}^{\ 2} + \tau_{31}^{\ 2}}{Q^2}$$

- 夹芯板面板起皱分析(Wrinkling)
  - 属于破坏分析的可选项，且默认为选中
  - 屈曲稳定系数被“加入”到安全系数中
    ($F_{effective}$ = SF_l * FoS * $F_{applied}$)

Laminate failure analyses – 5

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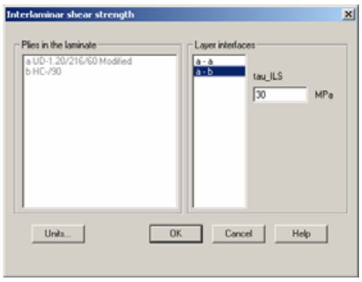
- 层间剪切破坏
  - 当存在层间剪切应力并定义了所有层间剪切强度(tau$_{ILS}$)时
  - 分层判断基于Hashin 准则 (忽略横向法向应力)



$$f_d = \frac{\tau_{31}^{\;2} + \tau_{23}^{\;2}}{\tau_{ILS}^{\;2}}$$

破坏模式

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- 初始和最终破坏模式是根据最大应力和最大应确定
- 1t = 主方向拉伸, 2c =横向压缩 , s = 面内剪切,…
- 如果根据最大应力/应变准则显示不同的破坏模式，将同时显示 (e.g. 2t/s)
- 破坏模式的近似判断是独立于失效载荷之外的, 今后版本中，破坏模式将会与破坏准则相关联 (e.g. Puck).

破坏分析结果

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LAMINATE FAILURE ANALYSES

- 在初次破坏或最终破坏分析中将进行层压板级别的破坏裕度分析(Margins of Safety,MoS; Factor of Safety ,RF)，得出剩余强度 (夹层板剪力，起皱屈曲，层间剪力等等)
  - MoS_{FPF} (RF_{FPF}) 是上述多个破坏形式结果的综合
  - <u>Note</u>: ESAComp 3.0之前的版本中 MoS_{FPF} 仅仅指 *FPF*，而 $MoS_{FPF/w}$ 指*FPF+wrinkling*
- 在层压板失效分析结果中各自给出 屈曲和层间剪切 MoS (RF)值
- 在分析结果中, 层压板破坏模式（laminate *failure mode*） 显示其最可能的破坏形式

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常量和变量载荷逼近

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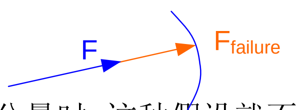
CONSTANT AND VARIABLE LOADS

- 通常的破坏极限近似计算都是假设载荷向量固定



- 当分析不同物理状况下的载荷分量时, 这种假设就不合理了. 比如:
  - 湿热载荷 vs. 机械外载
  - 静态载荷 vs. 动态载荷

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Partitioning of loads

- 在常量-变量加载近似中，施加的载荷被分为两部分：
- 变量部分表示可以增大该部分载荷，以计算出材料的破坏极限
- 安全系数(Factors of safety， FoS) 广泛应用于航空航天工程技术领域:

$$\{F\} = \{F^c\} + \{F^v\}$$

$$\{F\}_{\text{effective}} = SF\left(FoS^c\{F^c\} + FoS^v\{F^v\}\right)$$

  - 载荷常量和变量部分的安全系数各不相同
  - 稳定系数（Stability factor， SF） 是考虑到起皱和整体屈曲效应的系数

- 备用系数(Reserve factor ,RF) 与最终破坏载荷的关系如公式所示:

$$\{F\}_{\text{failure}} = FoS^c\{F^c\} + RF\,FoS^v\{F^v\} \quad , \quad RF > 0$$

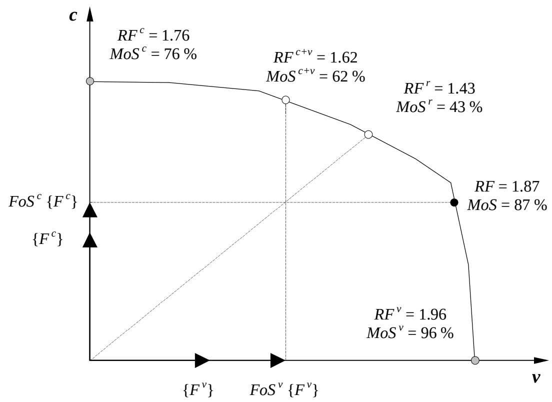
- 相应的安全裕度 (Margin of Safety，MoS)为:

$$MoS = RF - 1$$

- 常量和变量载荷的系数是独立的:

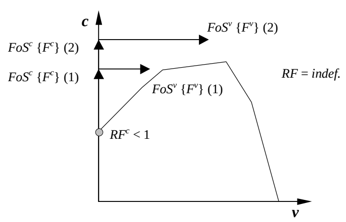
$$\{F^c\}_{\text{failure}} = RF^c\,FoS^c\{F^c\} \quad , \quad RF^c > 0$$
$$\{F^v\}_{\text{failure}} = RF^v\,FoS^v\{F^v\} \quad , \quad RF^v > 0$$

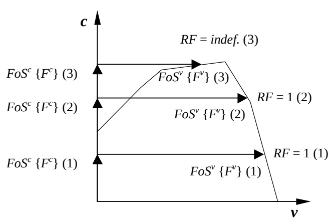
Graphical interpretation



Special considerations

- RF = INF (infinite，无穷大) 加载可以无限增加，无法达到破坏包线边界
- RF = INDEF (indefinite，不确定) when decreasing the magnitude of variable load does not lead to non-critical loading condition





Conclusions

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CONSTANT AND VARIABLE LOADS

- 在失效分析中采用常量和变量加载分析方式，同时施加多个载荷的情况下，可以在提供更丰富的相关信息
- 可以更好的预测可能的失效形式以及初始破坏单层
- 备用系数 RF^c 与 RF^v 有可能暗示，单独施加其他方式的载荷向量也会引发层压板失效
- 常量和变量加载分析只适用于层压板失效分析中

Laminate 2.5D behavior

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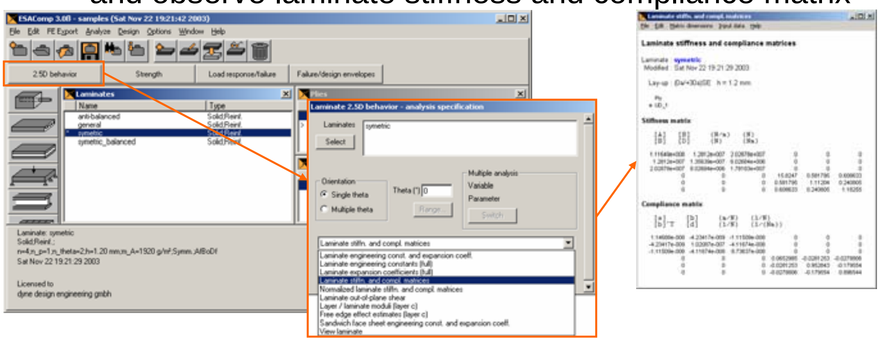
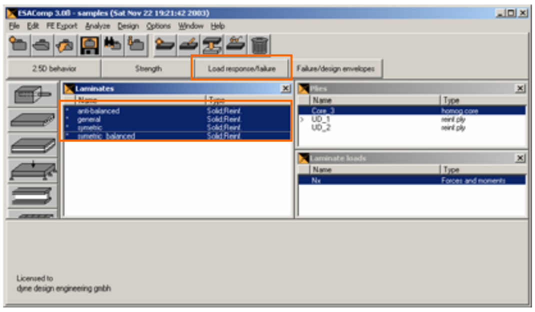
PRACTICAL EXAMPLES

- Which each laminate make a “2.5D behavior” analysis and observe laminate stiffness and compliance matrix



Laminate load response

- Select all laminates and make a “Load response/failure” analysis



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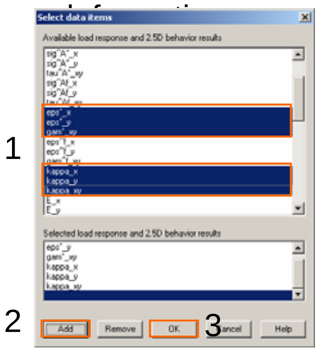
PRACTICAL EXAMPLES

Laminate load response

- Select eps° _x, eps° _y, eps° _xy, kappa_x, kappa_y and kappa_xy which correspond to mid-plane



$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \\ \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix}$$

Laminate load response

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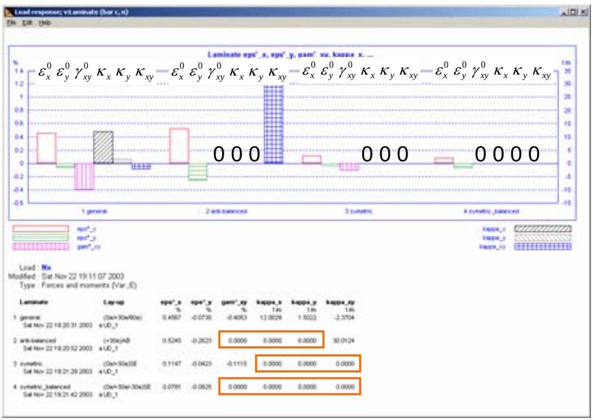
PRACTICAL EXAMPLES



Interlaminar shear

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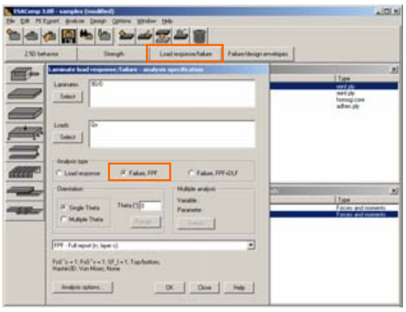
PRACTICAL EXAMPLES

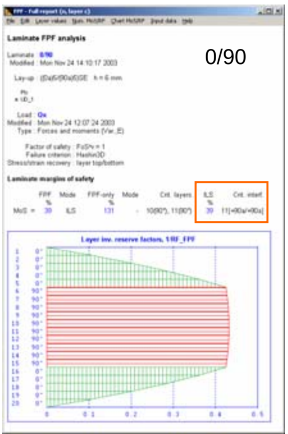
- Create two orthogonal laminates
  - "0/90" :
    $[0° /0° /0° /0° /0° /90° /90° /90° /90° /90°]_{SE}$
    define interlaminar shear strength of 30MPa
  - "90/0" :
    $[90° /90° /90° /90° /90° /0° /0° /0° /0° /0°]_{SE}$
    define interlaminar shear strength of 30 MPa
- Create a laminate load Q_x = 100 000 N/m

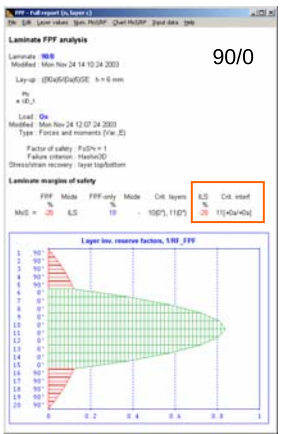
Interlaminar shear

- For each laminate “0/90” and “90/0” make a “load response / failure” analysis with the “Qx” load



Interlaminar shear





练习

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- 定义层压板常量载荷N_y=100000N/m，变量载荷N_x=100000N/m，检查某层合板在此载荷下的安全裕度
- 检查某蜂窝板在载荷M_x=4000Nm/m载荷下的安全裕度，稳定系数（stability factor）=1.5
- 层合板失效包线分析

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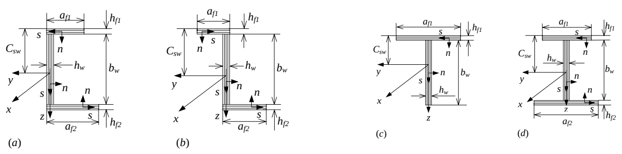
Plate analyses introduction

- 带给定边界条件的矩形板结构
- 分析内容: 横向载荷、面内载荷，以及自然震动频率分析
- 基于一阶剪切变形理论（FSDT）的分析
  - 采用 “DLR 方法”计算剪切刚度
  - 必须给出单层的G_{31} 和 G_{23} 模量
- 3.0 版能够处理非对称非平衡铺层板

- T, I, C 以及 Z 截面形状



- Hat cross section will be introduced later

Stiffener specification – 1

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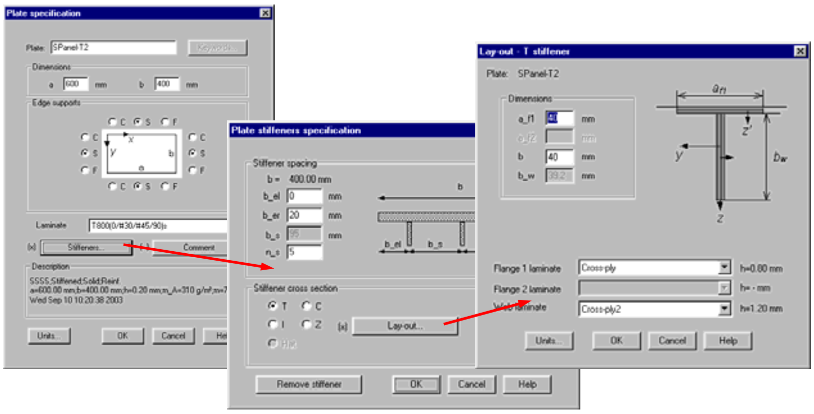
STIFFENED PLATE



Stiffener specification – 2

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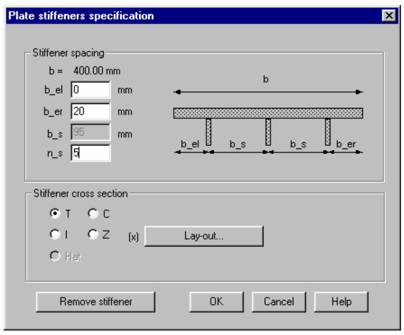
STIFFENED PLATE

- 加强筋位于底面的X方向
- 等距分布
- 两侧的边距可以不同



Stiffener specification – 3

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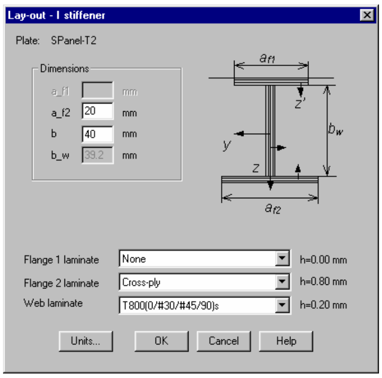
STIFFENED PLATE

- 加强筋截面设置与两截面设置类似
- 可以去除上檩条



FE modeling

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ANALYSIS APPROACH

- 自动生成相应的加强筋梁截面对象，但只能通过定义板结构进行修改
- 基于ESAComp内置有限元求解器进行板结构分析
- 采用改进的MITC4板壳单元建模
  - 早期版本采用相应板单元建模
- 加强筋用梁单元建模
  - 梁节点和相应板连接节点存在着偏移量

Boundary conditions – 1

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- 允许固支、简支和自由边的任意组合
- 固支
  - Z方向和所有转动自由度被固定
- 简支
  - Z方向以及垂直边界方向的转动自由度被固定
- Note: 边界条件对加强筋顶端有效 (板和梁间为刚性连接)

Boundary conditions – 2

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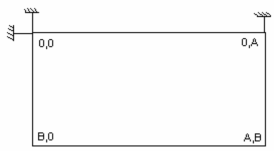
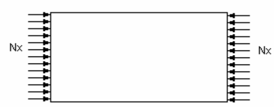
- 自动添加适当面内约束避免刚体运动



- Load application in buckling analysis
  - Note: Laminate in-plane load used in buckling

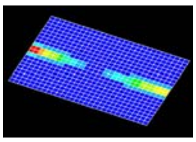


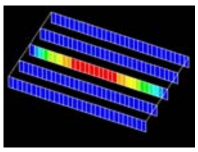
Post processing

- 每个单元都将进行层合板首层失效分析 (with wrinkling, core shear, ILS,…)
- 加强筋
  - 计算加强筋不同位置的应力和应变 (web-flange interface, web center,…)
  - 进行首层失效分析
  - 底部椽条和和腹板的局部屈曲采用近似方法分析

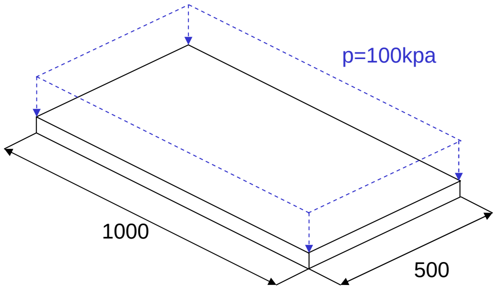
Result displays

- 基于OpenGL的3D轮廓线图形化显示
- 板和加强筋分别显示
- 对于夹芯板，包括了芯层和面板的计算结果
- 基于梁单元显示加强筋结果 (椽条和腹板的综合结果)

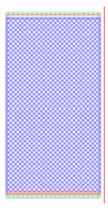




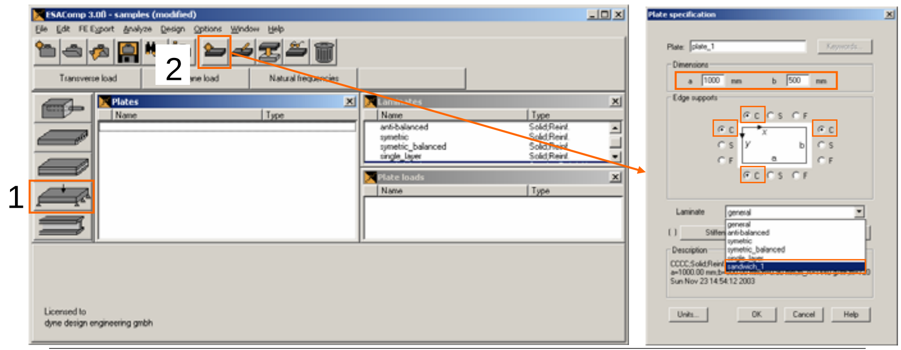
- Model



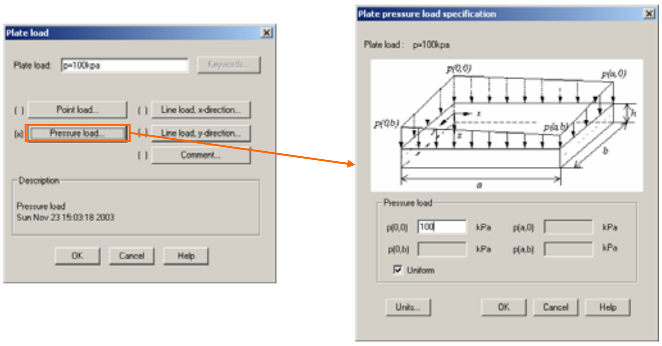
- Create a sandwich laminate: “sandwich_1”
  - $[0^\circ{}_a/90^\circ{}_a/0^\circ{}_b]_{SO}$
  - with a: UD ply of 0.3mm thickness
    b: Core ply of 20mm thickness



- Create a clamped sandwich plate “plate_1” with dimensions 1000x500 mm



- Create a uniform pressure plate load “p=100kpa” of 100 kPa



- Make a “Transverse load” analysis and choose the type of analyse: “Load response” or “Failure”

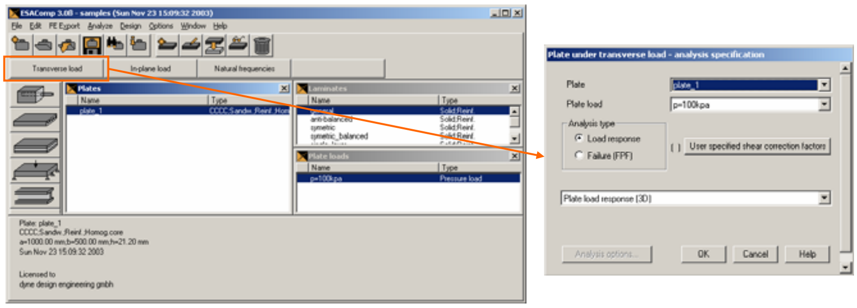


Plate analysis
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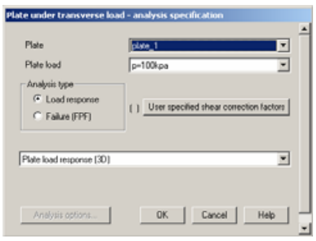
PRACTICAL EXAMPLES

- “Load response” analysis



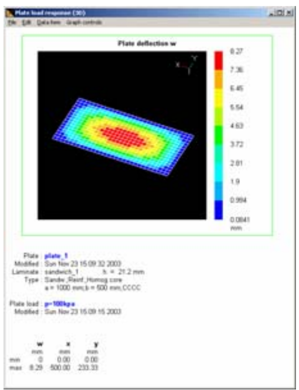


Plate analysis

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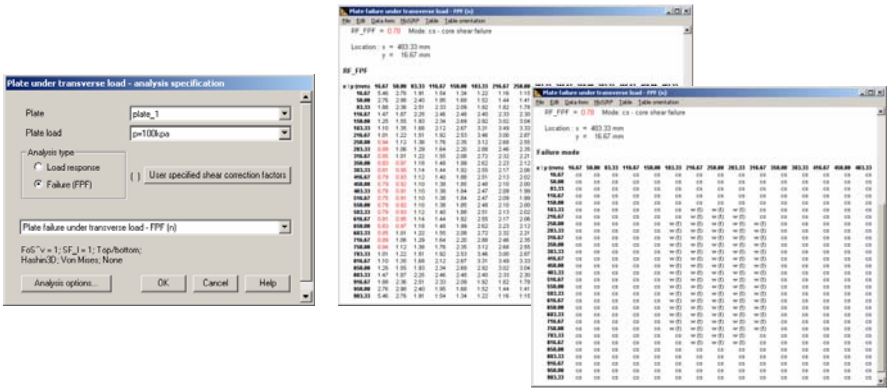
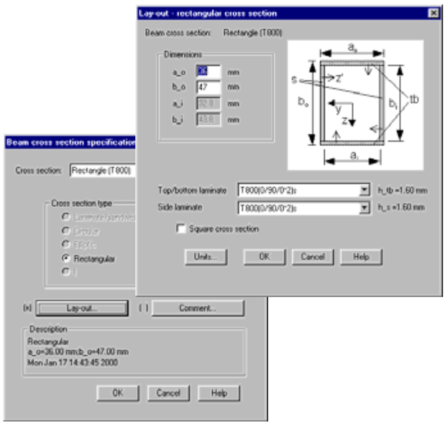
- "Failure" analysis



Beam Analyses

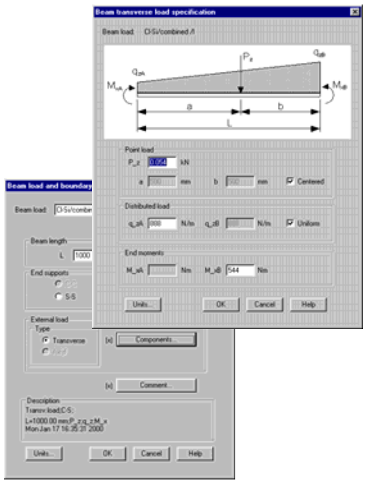
Beam cross sections

- 横截面类型: 层合板/夹芯板, 圆形,椭圆形,矩形, 以及 “工”字型
- 横截面必须关于Y-Z平面对称
- 必须是薄壁梁 (10%)
- 不支持楔型梁



Beam loads

- 可以设置
  - 梁长度
  - 两端支撑条件 (C, S, F)
  - 轴向和横向载荷
- 横向载荷可能包括点载荷、分布载荷以及端点力矩
- 轴向载荷包括力以及位移条件



Beam analyses – 1

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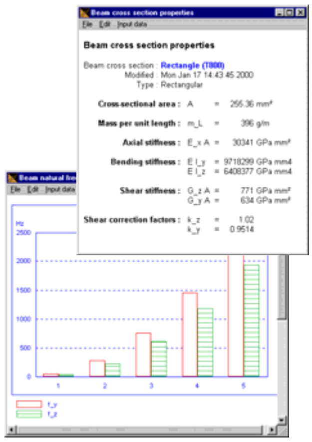
- 根据分析类型确定是否考虑剪切效应影响
- 分析类型
  - 截面属性
  - 横向载荷下的载荷响应和失效分析 (首层失效分析)
  - 轴向载荷下的首层失效分析和屈曲分析
  - 自然振动频率



Beam analyses – 2

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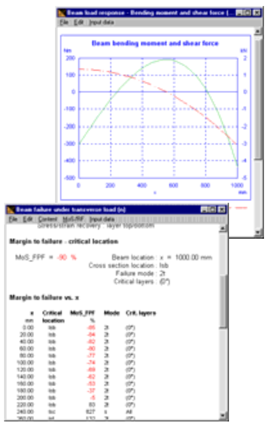
- 横向载荷分析过程
  - 计算沿长度分布的弯矩和剪力
  - 仅计算在可能的期限部位的截面应力状态
  - 进行首层失效分析
- 不考虑缘条/腹板的局部屈曲 (与加筋板分析不同)



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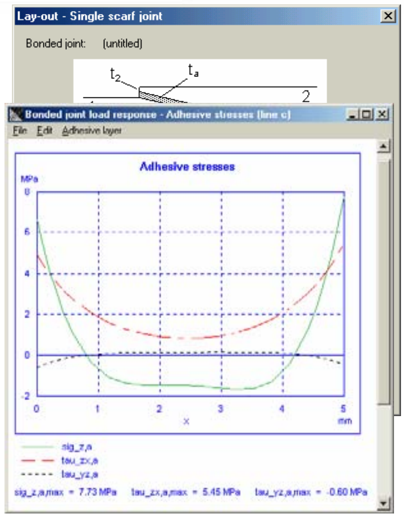
胶接接头分析

单面、双面搭接、嵌接等多种接头类型

线性/非线性的拉、压、剪切胶接弹簧模型

纵向加载，弯曲，面内/面外剪切

接头变形，力，力矩，胶接应力，脱粘的安全裕度以及面内失效裕度



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机械连接

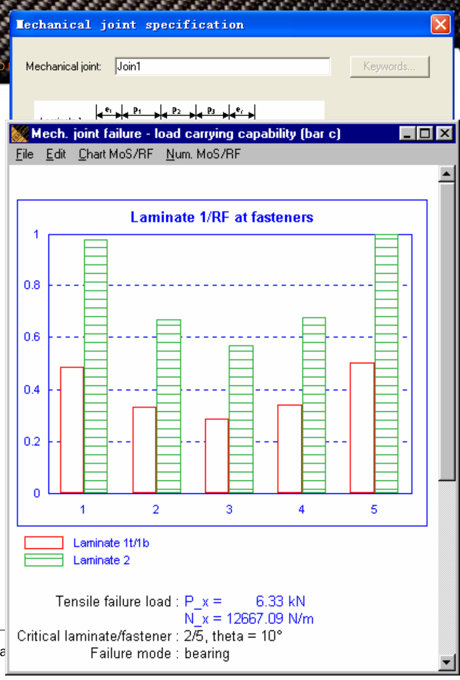
非轴向载荷分析

单面和双面搭接

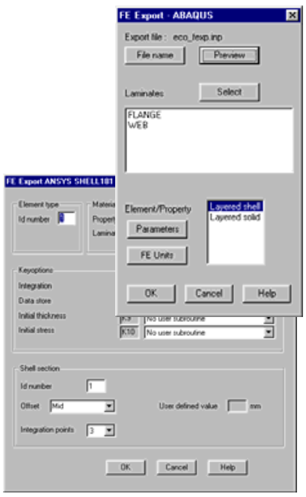
考虑销钉弯曲影响

销钉任意分布状态

紧固件载荷状态，联结孔的应力、应变，失效安全裕度，失效模式预测



FE Interfaces



- 支持的FEA软件:
  - ABAQUS
  - ANSYS
  - I-DEAS
  - MSC.Nastran/Patran
  - NISA、ASKA (currently export only)
  - LS-DYNA (under development)
- Other FE codes can be supported upon request

Export from ESAComp to FE Software

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

FE INTEGRATION

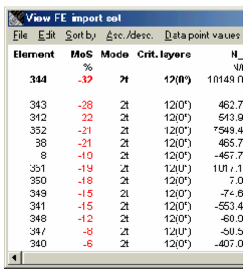
- 输出材料数据
  - 实体模型
  - 含层合板的板壳单元
- 输出层合板数据
  - 复合材料铺层的板壳单元材料属性和铺层结构
  - 对普通壳单元可输出刚度矩阵
- 输出能够被有限元软件读取的文本格式数据

Import from FE software to ESAComp

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

FE INTEGRATION

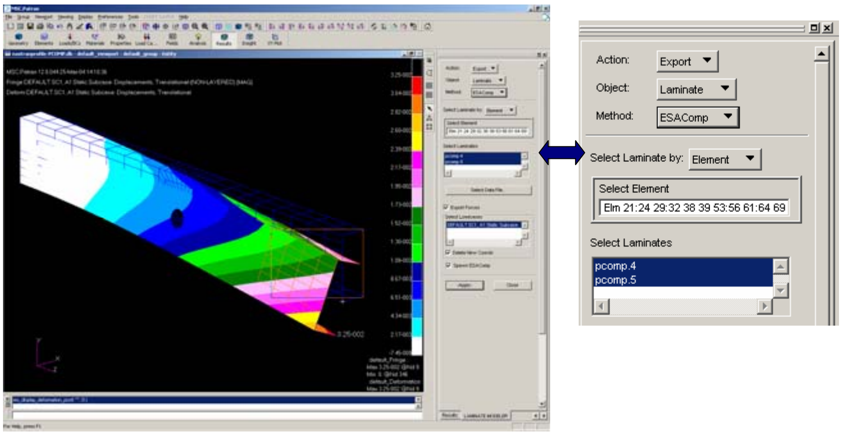
- 壳单元、积分点以及节点的应力应变状态
- ESAComp复合材料工具后处理
  - 单层级别的详细分析
  - 失效分析
    - 多种失效准则
    - 各种失效模式:
      屈曲, 芯层剪切, 层间剪切
- 对所有数据点实施失效分析
- 可以对个别数据点进行详细分析



ESAComp – MSC.Patran LM Interface

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

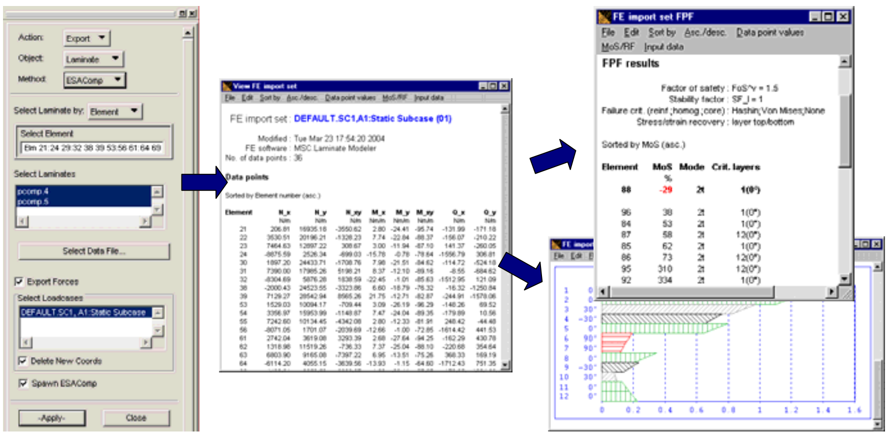
FE INTEGRATION



ESAComp – MSC.Patran LM Interface

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

FE INTEGRATION



Further ESAComp–MSC integration (2)

THE COMPOSITES DESIGN SOFTWARE BY COMPONEERING

- More direct access from Patran to ESAComp (e.g. layer charts for selected element with a "click")