EFFECTS OF DEFECTS IN COMPOSITE STRUCTURES

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DESIGN CRITERIA

FIRST PLY FAILURE
- Design ultimate strain (DUS) is strain for first ply failure

STATE OF THE ART
- DUS is failure strain of laminate with 0.25-in. hole

POSSIBLE
- DUS is failure strain of laminate with low-energy impact damage
- Buffer and softening strips used

UPPER BOUND
- DUS is failure strain of laminate
- Stress concentrations designed around least conservative

PREPREG DEFECTS

HOLLOW FIBERS
EXCESSIVE VARIABILITY IN FIBER PROPERTIES
RESIN-STARVED OR FIBER-STARVED AREAS
WRINKLES, WAVINESS, MISCOLLIMATION
FOREIGN PARTICLES, CONTAMINATION
PILLS AND FUZZ BALLS
NONUNIFORM AGGLOMERATION OF HARDENER
PREPREG OUT OF SPECS.
DEFECTS IN LAMINATES

HOLLOW FIBERS
FIBER BREAKS
EXCESSIVE POROSITY, voids
RESIN-RICH AND RESIN-STARVED AREAS
FIBER WAVINESS, WRINKLES, MISCOLLIMATION
FOREIGN PARTICLES, CONTAMINATION, INCLUSIONS
INCOMPLETE AND/OR VARIABLE CURE
WRONG STACKING SEQUENCE
DENTS, TOOL IMPRESSIONS, SCRATCHES

LAMINATE POROSITY

STUDIED EXTENSIVELY
MATRIX DOMINATED PROPERTIES DEGRADED (DELAMINATION NOT INCLUDED)
  5% STRENGTH REDUCTION FOR 1% POROSITY
  50% LIFE REDUCTION FOR 1% POROSITY
FIBER-DOMINATED PROPERTIES NOT AFFECTED
DELAMINATION GROWTH AFFECTED - NOT WELL DOCUMENTED
MOISTURE ABSORPTION
  EQUILIBRIUM MOISTURE LEVELS INCREASED
  AGGRAVATES THERMAL SPIKE PHENOMENON
EFFECT OF PLY GAP DEFECT

(REF. 1)

\([(0/45/90/-45)^{S_2}]\) LAMINATE
- 16.9% STRENGTH REDUCTION FOR GAP(S) IN 90 PLIES
- 8.7% REDUCTION FOR GAP(S) IN 0 PLIES

\([(0/45/0/-45/0)^{S_2}]\) LAMINATE
- 6.5% STRENGTH REDUCTION FOR GAPS IN 0 PLIES

(REF. 2)

\([(0/\pm 45/90)^{S_2}]\) LAMINATE
- 12.8% STRENGTH REDUCTION FOR GAPS IN OUTER 45 PLIES

\([(0/-45/0)^{S_2}]\) LAMINATE
- 6.2% STRENGTH REDUCTION FOR GAPS IN OUTER 45 PLIES

DEFECT CRITICALITY - BENIGN FOR DESIGN ULTIMATE STRAIN 0.7%

EFFECT OF PLY WAVINESS DEFECT

(REF. 3)

SURFACE 0 PLY WAVINESS IN \([(0/45/90/-45)^{S_2}]\) LAMINATE

STATIC TENSILE STRENGTH REDUCTION
- 10% FOR SLIGHT WAVINESS
- 25% FOR EXTREME WAVINESS

FATIGUE LIFE REDUCTION
- AT LEAST A FACTOR OF 10
- CONSISTENT WITH STATIC STRENGTH REDUCTION

DEFECT CANNOT BE FOUND BY STANDARD NDE

STRENGTH LOSS CAN BE PREDICTED BY ASSUMING LOSS OF LOAD CARRYING CAPACITY DUE TO THE WAVINESS

DEFECT CRITICALITY - INSUFFICIENT DATA FOR ACCURATE ASSESSMENT
- SHOULD BE BENIGN FOR DESIGN ULTIMATE STRAINS 0.7%
MACHINING DEFECTS

EDGE DELAMINATIONS
OVERSIZE HOLES
UNDERSIZE HOLES
TILTED HOLES
TILTED COUNTERSINKS

EDGE NOTCHES AND SURFACE NOTCHES
HEAT-DAMAGED MACHINED EDGES
FIBER BREAK-OUT ON HOLE EXIT SIDE
OUT-OF-ROUND HOLES
IMPROPER DEPTH OF COUNTERSINKS

DENTS, FIBER BREAKING FROM IMPACT
TEAROUT OR PULL-THROUGH IN COUNTERSINKS

EFFECT OF SURFACE NOTCHES

EXPERIMENTAL DATA

STATIC STRENGTH REDUCED UP TO 50%
LOCAL DELAMINATION AT NOTCH
FATIGUE LOADING REDUCES STRESS CONCENTRATION
RESIDUAL STRENGTH HIGHER THAN STATIC STRENGTH
DATA AVAILABLE FOR VARIOUS STACKING SEQUENCES

ANALYSIS

ECCENTRIC BEAM MODEL PREDICTS STRENGTH REDUCTION
STRENGTH REDUCTION IS SMALL FOR SIZES EXPECTED IN SERVICE

DEFECT CRITICALITY

NOT CRITICAL FOR DUS < 0.7
BOLTED ASSEMBLY DEFECTS

OVERTORQUED FASTENERS  IMPROPER FASTENER SEATING
MISSING FASTENERS       FASTENER INSTALLATION DAMAGE

OVERSIZED AND UNDERSIZED FASTENER

BONDING DEFECTS

ADHESIVE POROSITY
MISCURE
ADHESIVE-STARVED AREAS
IMPROPER SURFACE PREPARATION
REFERENCES

