

Bonded Structures Industry Survey

Curtis Davies

FAA Technical Center

Atlantic City International Airport, NJ

Acknowledgement and Scope

- Wichita State University / NAIR
Wichita, KS
 - John Tomblin
 - Kristin Strole
 - Gabrielle Dodosh
- This review only shows the top level information. More detailed analysis of the survey can be found in the FAA Technical Report which will be issued later this year.

Survey Motivation

- Bonding is used in numerous manufacturing and repair applications involving aircraft structures
- This includes existing commercial and military applications: small airplanes, transport aircraft, rotorcraft and fighter jets.
- The technical issues for bonding are complex and require cross-functional teams for successful applications.

Survey Focus

- The FAA organized this effort to benchmark bonded structures
- The primary objective is to document the technical details that need to be addressed for bonded structures, including critical safety issues and certification considerations.
- Identify examples of proven engineering practices, which have been used to address selected technical details, will be documented as a secondary objective.
- The process to benchmark existing technology will also provide directions for future research and development in the field.
- A strong interface with the industry, other government groups and academia is needed to adequately benchmark bonded structures.
- Such an approach will yield documents that provide a practical engineering guide, with educational value for an expanding work force.
- Over time, the FAA will continue to work with industry and other government agencies in drafting consistent policy and guidance for bonded structures, which has a basis in successful industry applications.

Survey Structure

- Focus Areas
 - Background Information
 - Material and Process Control
 - Material and Process Qualification
 - Material Control
 - Process Control
 - Manufacturing and Design Integration
 - Design and Analysis
 - Manufacturing
 - Allowables and Design Data
 - Product Development, Substantiation and Support
 - General Experiences and Concerns
- Still seeking additional viewpoints
 - Take the survey
 - <http://www.niar.wichita.edu/faasurvey>

Background Information Summary

All results are based on 57 responders from 38 companies

Perspectives expressed in this survey are based on the following:

	Percent of Responders
Personal Insights	21.0
Personal experience	40.3
Functional team experience	17.5
Organizational position	21.0

Background Information Summary

All results are based on 57 responders from 38 companies

What is your job function as related to adhesive bonding:

	Percent of Responders
Materials and Processes	50.8
Design	8.0
Manufacturing	8.0
Analysis (Structural Integrity)	29.8
Regulator	7.0
R & D	3.0
Other	3.0

Background Information Summary

All results are based on 58 responders from 38 companies

How many years have you been involved in adhesive bonding?

Minimum	Maximum	Average	Std. Deviation
2.0	47.0	17.8	9.4

Background Information Summary

All results are based on 57 responders from 38 companies

What is your business area?

	Percent of Responders
Original Equipment Manufacturer	43.8
Bonding Outsourcing Shop	0.0
Repair Facility	12.2
Regulatory Agency	5.2
Customer	0.0
Researcher/Academia	19.2
Composite producer	3.5
Consultant	7.0

Background Information Summary

All results are based on 55 responders from 38 companies

- What aircraft have bonded structures, are manufactured, maintained or controlled by your company or government group?

	Percent of Responders
Primary	87.2
Secondary	81.0
Tertiary	63.3

Background Information Summary

All results are based on 57 responders from 38 companies

Does your company deal with?

	Percent of each Company
Commercial	70.1
Military	64.9
Other	3.5

Background Information Summary

All results are based on 63 responders from 38 companies

Does your company qualify new material and/or bonding processes?

	Yes	No
Percentage	77.8	22.2

Do you use material and bonding processes qualified by other companies?

	Yes	No
Percentage	77.8	22.2

Do you control the quality of materials or processes used for bonded structures?

	Yes	No
Percentage	73.2	26.8

Background Information Summary

All results are based on 63 responders from 38 companies

Do you certify or approve designs?

	Yes	No
Percentage	73.2	26.8

If yes, which of the following are the designs intended:

New Products	77.1
Product Modifications	65.7
Repairs	77.1

Background Information Summary

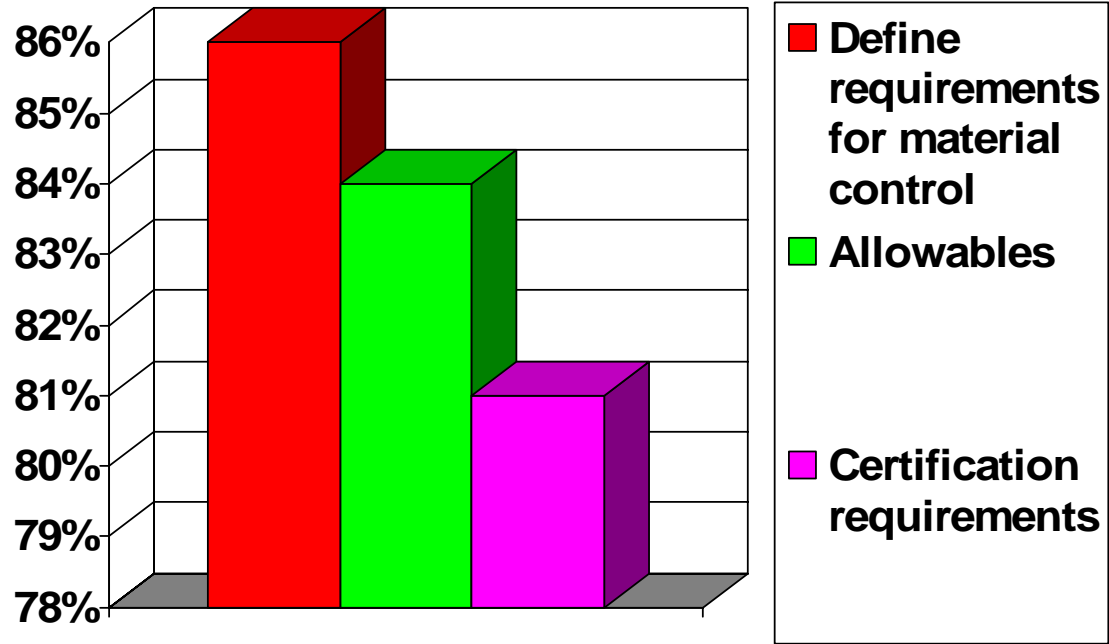
All results are based on 63 responders from 38 companies

Are you involved in maintenance actions that involve bonded repairs or structures?

	Yes	No
Percentage	80	20

Materials and Process Control

The majority of responders agreed that the general purpose for the adhesive qualification testing is to define requirements for material control, allowable and certification requirements.

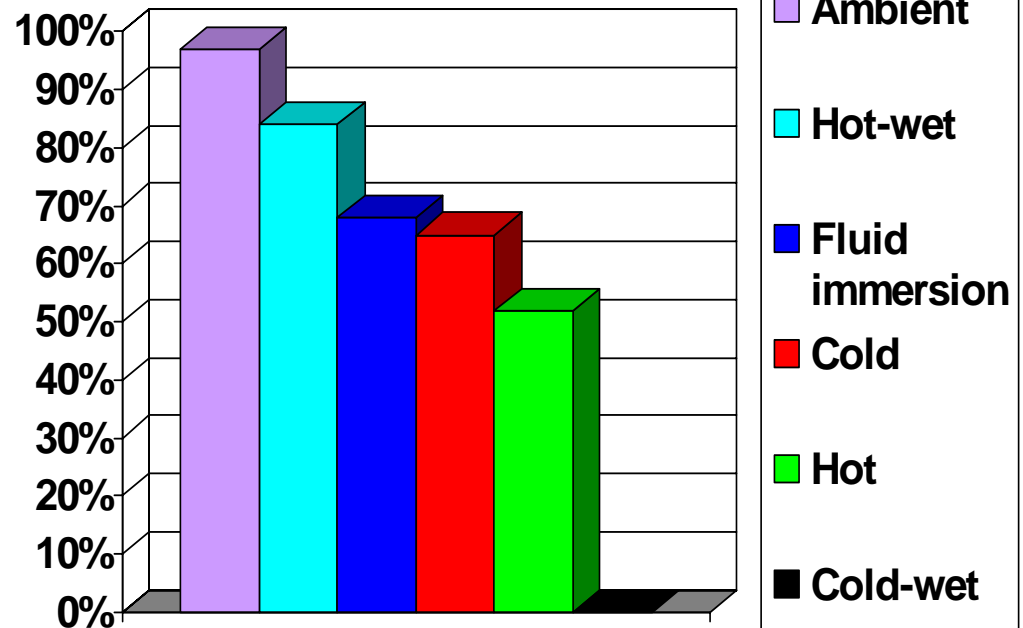


Materials and Process Control

Material and Process Qualification

- The most common number of adhesive batches used for qualification is three
- 86 percent of respondents used lap shear to test for adhesive qualification

- The typical test matrix consists a mix between each of the following:



Materials and Process Control

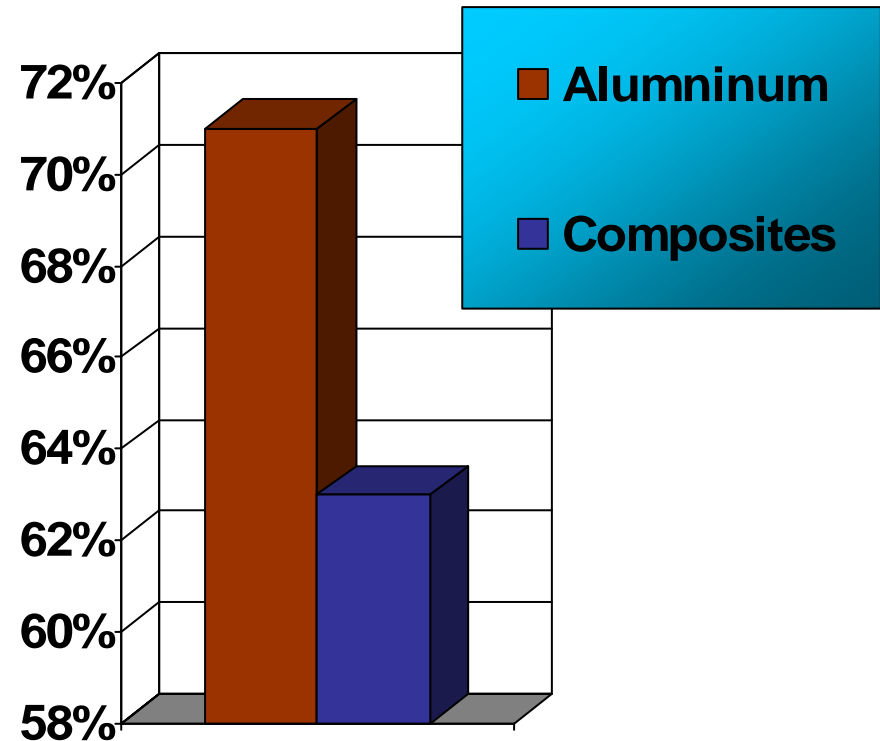
Material and Process Qualification

- For multi-part adhesive compounds, 72 percent of responders said the test matrix considered nominal mix ratios and 24 percent said it explored the limits of acceptable mix ratios .
- Responses indicate that the test matrix was accurately characterizing the requirements.

Materials and Process Control

Material and Process Qualification

- Each of the 38 responders said adhesive qualification includes mechanical tests of a bonded joint. These tests incorporated both metal and composite adherends.



Materials and Process Control

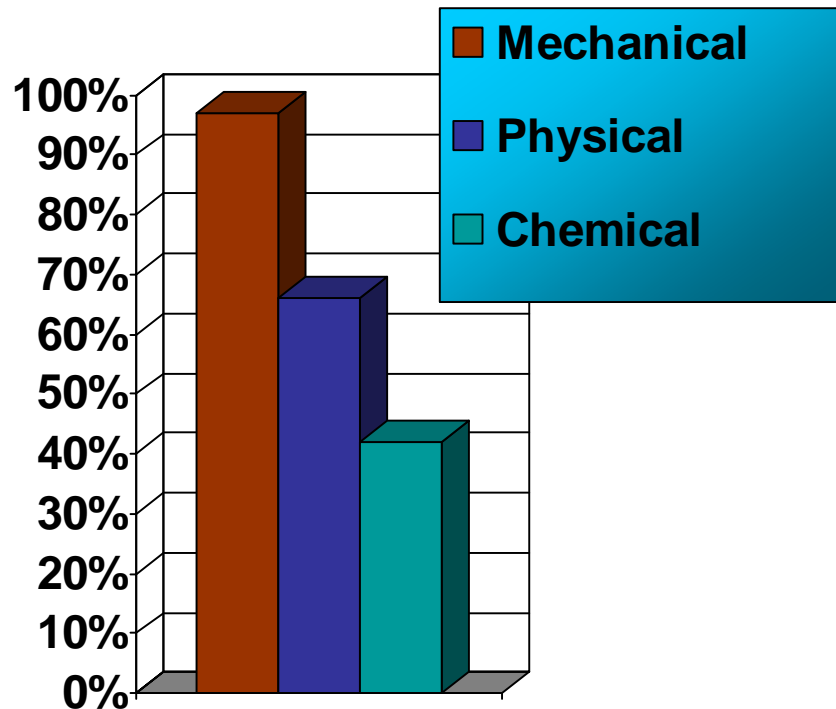
Material and Process Qualification

- 60 percent of respondents said the adhesive nonlinear shear stress-strain response was not characterized during testing

- 53 percent of respondents said they used the thick adherend test and KGR gages, or something similar

Materials and Process Control

Material and Process Qualification

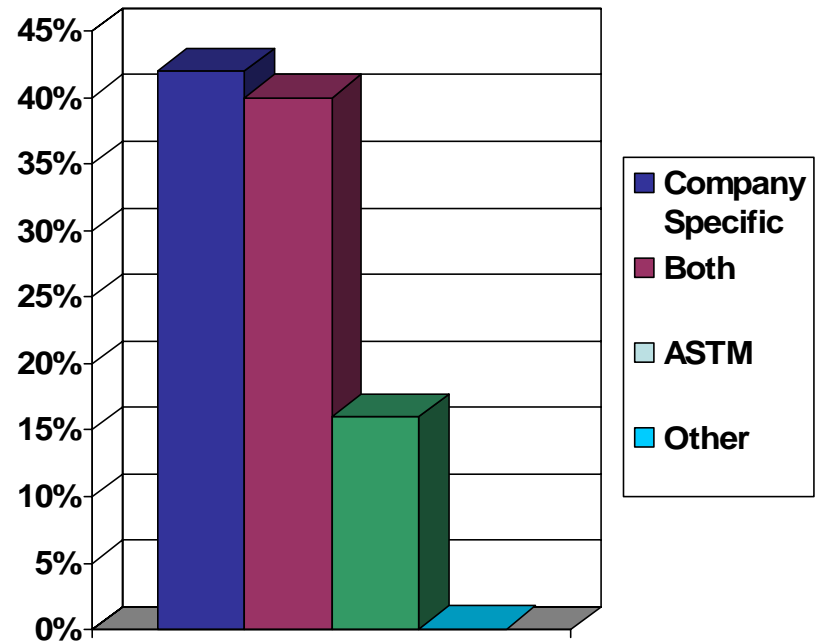


- 97% of respondents said they use Mechanical tests for bonding process qualifications, with Physical at 66% and Chemical at 42%
- More respondents agreed that surface preparations were included in the qualification test plan

Materials and Process Control

Material and Process Qualification

- A majority of respondents said both moisture and temperature were, and should, be included in the adhesive bonding process qualification test plan.
- A majority of respondents said their qualification tests can be traced back to both ASTM and their Company.



Materials and Process Control

Material Control

96 percent of respondents said mechanical properties are included in the contents of specifications used for adhesive material procurement and control, with 92 percent stating physical properties

A majority of responders said material acceptance tests are done by suppliers

93 percent said they use mechanical tests for acceptance testing, compared to 80 percent who cited physical

Materials and Process Control

Material Control

A majority of responders said they either agreed or strongly agreed that the limits from adhesive qualification data are used for acceptance requirements defined in the specification

A majority of responders said their acceptance tests can be traced back to ASTM test methods

The adherend and adhesive thickness the responders used for acceptance tests is the same as those being used in production

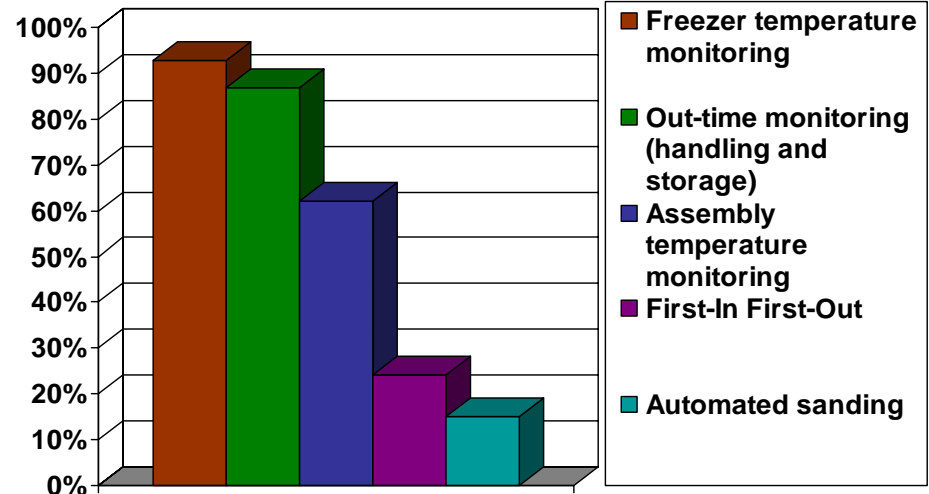
Materials and Process Control

Material Control

Respondents were split on whether environmental effects are part of testing acceptance. 44% agreed, compared to 38% who disagreed and 18% who neither agreed nor disagreed

The results were also split on whether peel ply materials are used for surface preparation and are subjected to the same controls as adhesives

Most responses indicated that freezer temperature monitoring and out-time monitoring were the main procedures they used in controlling adhesive storage and handling from purchase until use



Materials and Process Control

Process Control

70 percent of respondents use in-process monitoring for processing and 62 percent use a witness panel

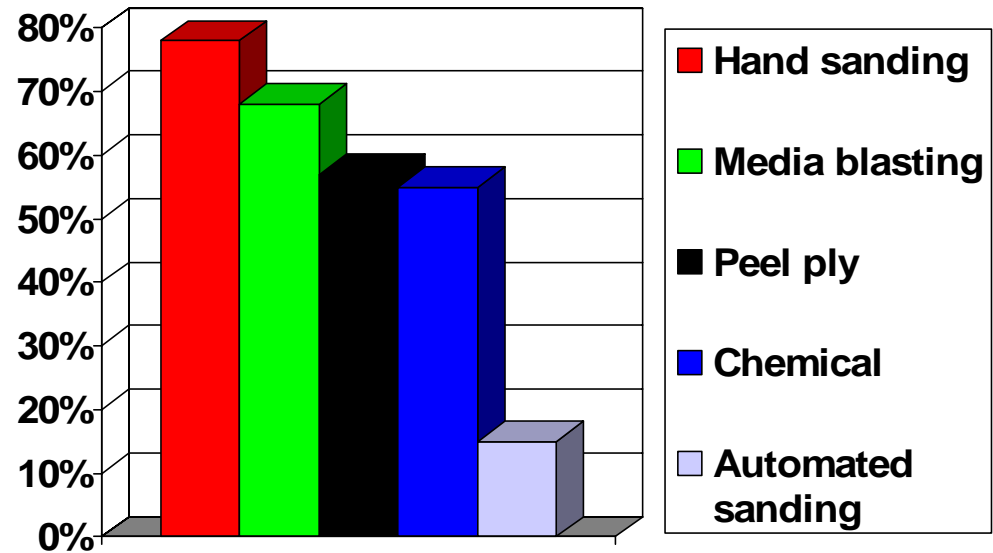
A majority of individuals agreed that mechanical tests are performed for bonding process control purposes

Respondents also agreed that Pre-bond moisture of the substrates is controlled in their process

Materials and Process Control

Process Control

The majority of responses indicated that 78 percent of the responding companies use hand sanding and 68 percent use media blasting as part of their surface preparation. Peel ply, chemical and automated sanding follow accordingly



Materials and Process Control

Process Control

In the case of paste adhesives, the majority of responses indicated that mixing variables are controlled by weight during production, as opposed to chemical analysis and test coupons

Out of 45 responses, the majority said they have time constraints for the following steps leading up to cure:

- * 77 percent for Adhesive application – adhesive cure
- * 71 percent for Surface preparation – primer and Primer Application-Adhesive cure
- * 57 percent for Surface preparation - adhesive

Materials and Process Control

Process Control

Based on the responses, the majority said the bonding process cure cycle is controlled by BOTH time and temperature

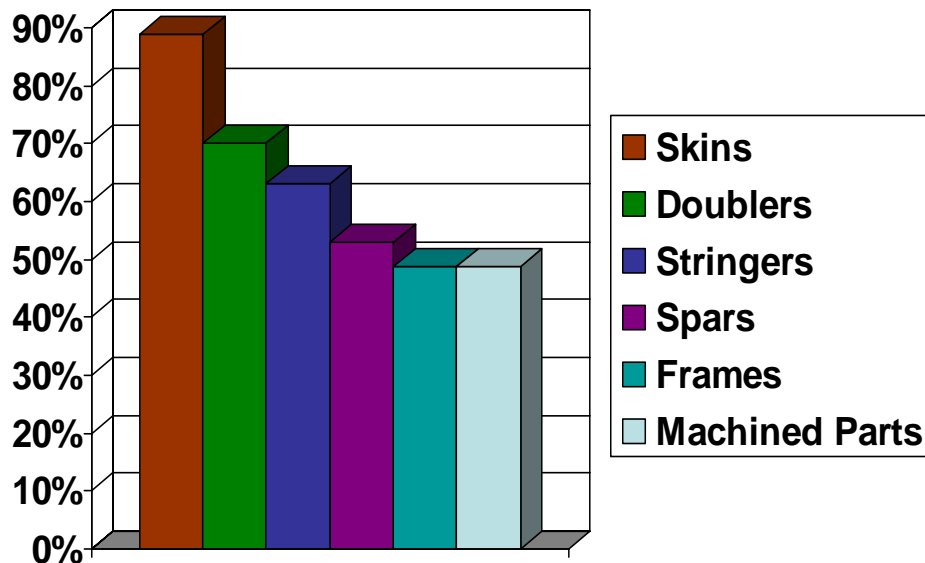
37 out of 49 responses agreed or strongly agreed that there are indicators to demonstrate temperature and pressure at the bond line

An overwhelming majority of responses indicate that Nondestructive Inspection DOES play a role in bond process control

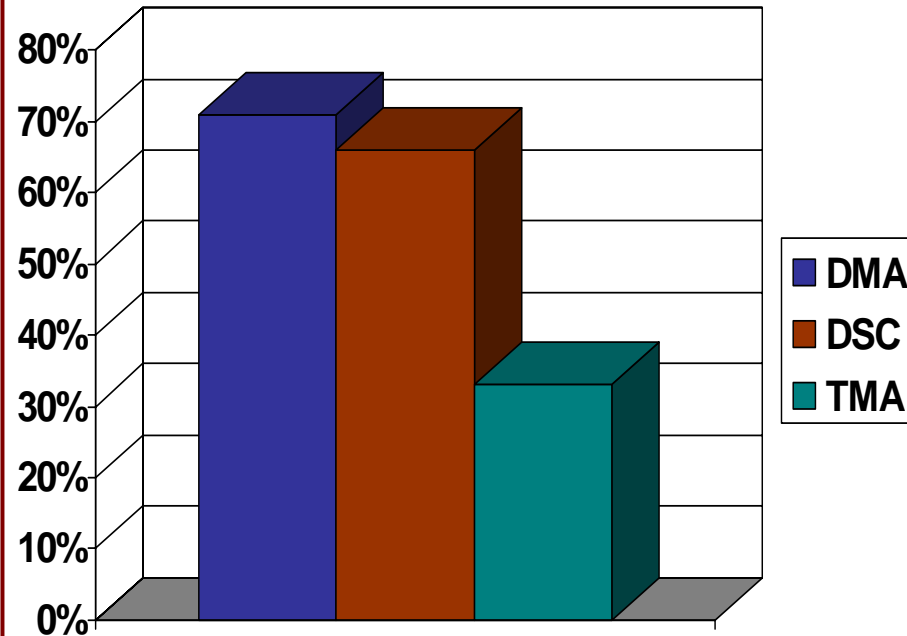
Manufacturing and Design Integration

Design and Analysis

Most responders said they use a mix of skins, doublers, stringer, spars, frames and machined parts use bonding for manufacture and/or repair. The percentage breakdown is below:



Tg is measured primarily by DMA, followed by DSC and TMA



Manufacturing and Design Integration

Design and Analysis

- Responses varied on whether any analysis codes were used, with slightly over 50 percent agreeing compared to 46 either disagreeing or having no opinion.
- More than 50 percent of respondents said their predictions distinguish cohesive failures in the adherend or adhesive.
- A majority of respondents don't agree that adhesion failures between the substrate and adhesive can be predicted.
- Responders overwhelming said they make a concentrated effort to minimize peel stresses in the design of bonded joints.

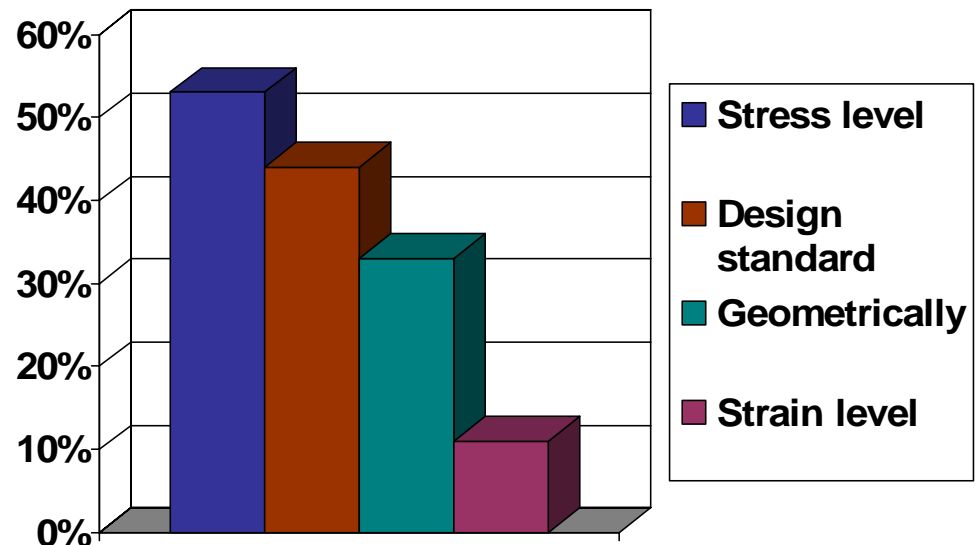
Manufacturing and Design Integration

Design and Analysis

A majority of respondents indicated that their analysis accounts for residual stresses in the bonded joint

Rivets were the number one fail-safe design feature used to reduce the risk of weak bonds in structures.

The overlap length used in design is primarily sized by stress level (53 percent), followed by design standard and geometrically. Results are indicated below:



Manufacturing and Design Integration

Manufacturing

- A majority of respondents said the control both humidity and temperature are important
- 49 percent of respondents said they use a vacuum bag for adhesive bonding, followed by press at 23 percent and matched tooling at 20 percent
- **Most respondents AGREED that cured part dimensional tolerance and warpage is controlled**

- **Responses indicated an equal split of whether verifilm runs are performed to confirm the fit of mating surfaces (50/50)**
- **Most respondents AGREED that the materials and processes qualified for structures impose strict time limits for adhesive application steps**
- **The majority said they DO NOT handle large-scale surface preparation and adhesive application different than laboratory scale**

Manufacturing and Design Integration

Manufacturing

- 88% strongly agree or agree that there are handling/storage constraints and disposal guidelines for materials used in surface preparation (e.g. solvents, etc . . .)
- 69 percent of respondents said bondline thickness is controlled by scrim cloth, followed by glass beads at 36 percent, microballoons at 34 percent, shims at 18 percent and stop blocks at 10 percent

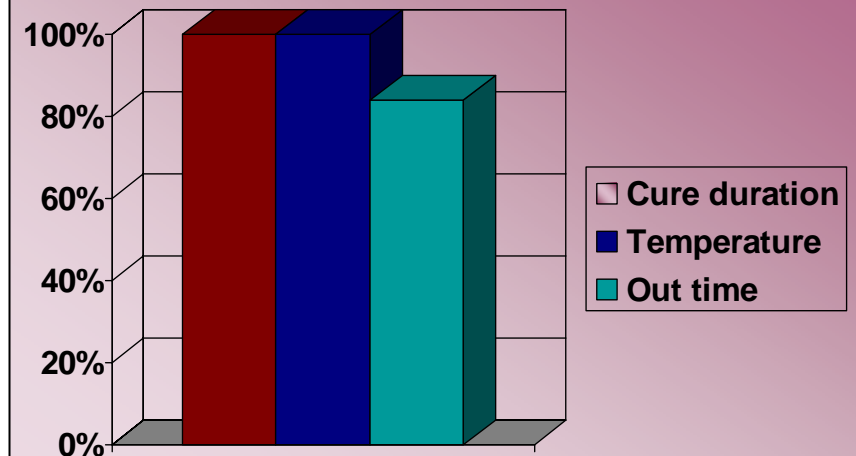
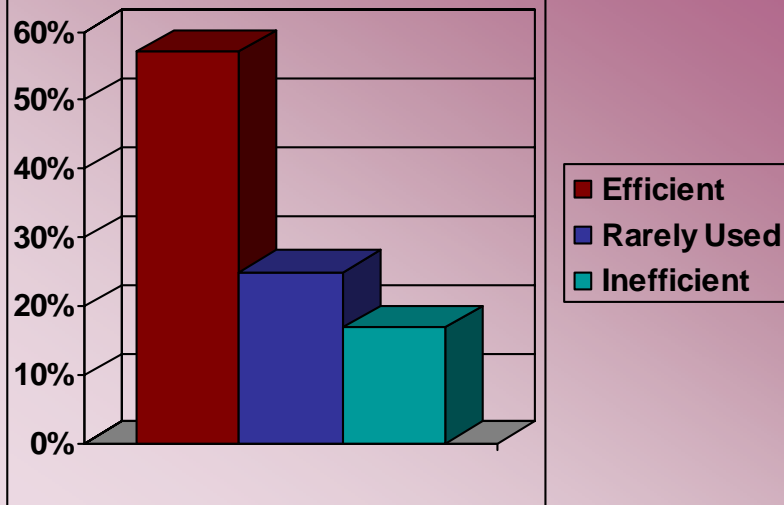
- Responses indicated that 80 percent of companies inspect bonded parts with UT, followed by 79 percent who said visually, and 57 percent who said tap. Radiography came in last with 19 percent
- 100 percent of individuals said they use size as the classification to control defects. Followed by number at 76 percent and proximity at 71 percent

Manufacturing and Design Integration

Manufacturing

The majority of respondents said their company's method for dealing with bonded structure discrepancies was efficient

100 percent of respondents said cure duration and temperature were significant records taken during the bonding process



Manufacturing and Design Integration

Allowables and Design Data

Seventy-seven percent of responders use lap shear as an allowable, with thick adherend following at 50 percent and bulk adherend at 31 percent

Results indicate that most companies use the same design data to support the design of their bonded structure. The most commonly used is standard adhesive thicknesses, followed by lap widths and standard joint configurations

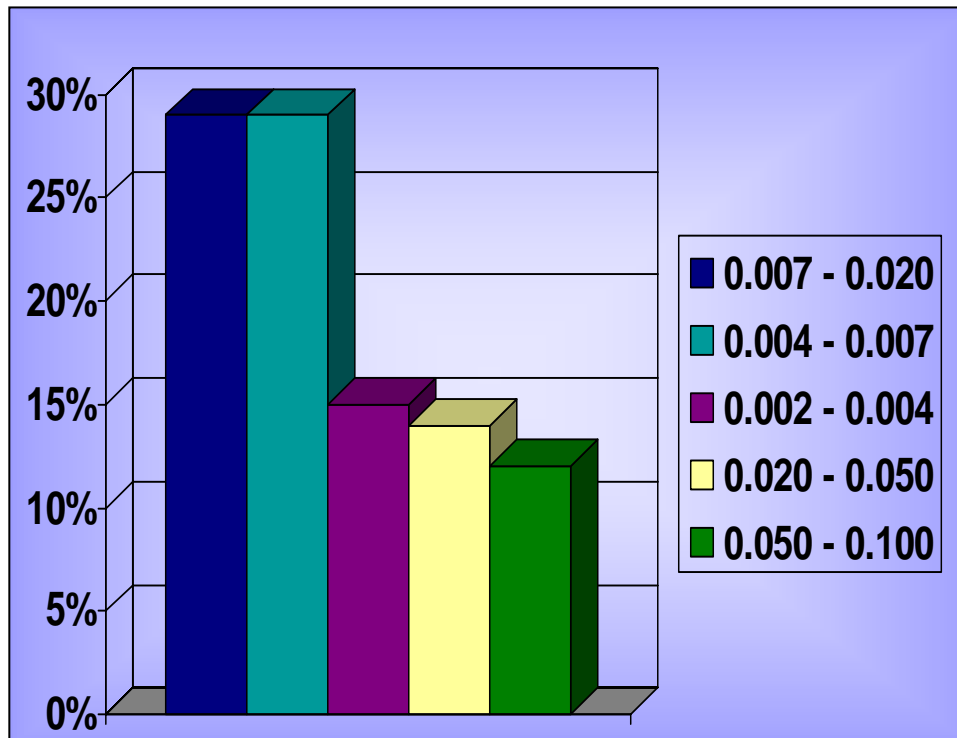
Most responders said environment was and should be considered in allowables design

A majority of responses said the bond overlap used in testing was $\frac{1}{2}$ inch

Responders agreed that if a number of overlap lengths exist in the design, the test plan should be representative of all the overlaps

Manufacturing and Design Integration

Manufacturing



The majority of respondents said 0.007 - 0.020 and 0.004 - 0.007 inches should be used for bonded joint characterization.

The majority of responders said their design has tolerances specified for quality control

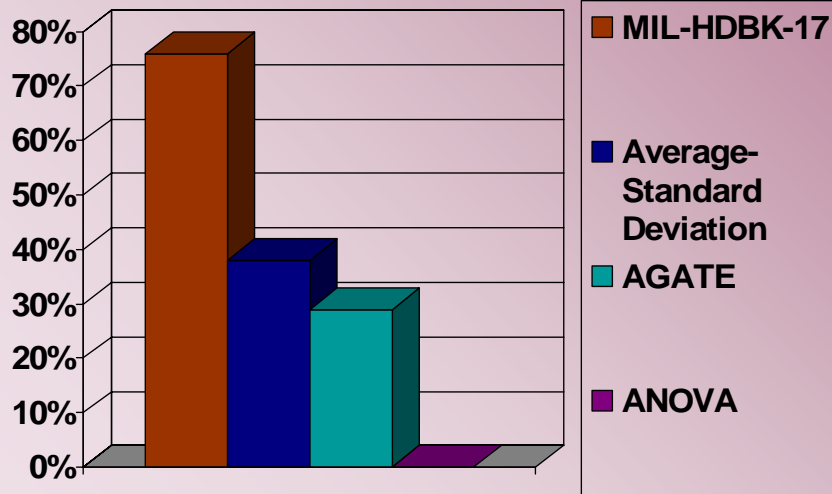
AND

They test for more than just the maximum thickness for allowables characterization

Manufacturing and Design Integration

Manufacturing

Most responders said they use the MIL-HDBK-17 to develop statistical allowables. See graph below for complete breakdown:



Most respondents agree that data from qualification testing or other repetitive bonded joint tests are used to establish statically based design allowables

Responders also agreed that a lower “minimum bond strength design value” is set based on experience and test data (e.g., 500 psi)

The majority said they verify the adequacy of the design by combining the value to peak shear and average shear stresses

Product Development, Substantiation and Support

Based on the experience of responders, the product development (through certification) lead times for bonded structures are longer than for conventional structures that use mechanical fastening

Most companies said the scale of testing that yields the most meaningful data for bonded structure development, substantiation and support is different in every case

In regards to how critical the bonded joint is classified, responses indicate an equal distribution of loads and applications

Most companies agreed that the strength and damage tolerance of the bonded structure should be characterized during a full-scale test and that analysis validation takes place at this level

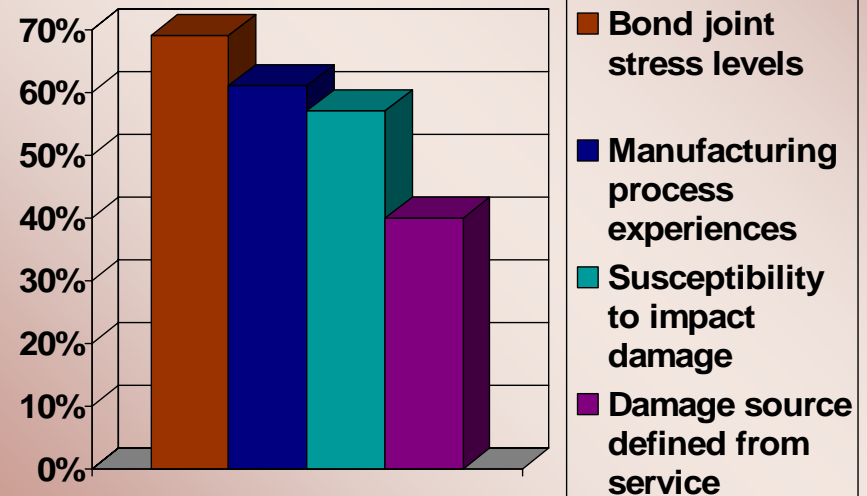
Product Development, Substantiation and Support

Respondents agree that long-term environmental exposure and durability should be substantiated for bonded structures

Most companies have found that small-scale tests have meaning to service experiences

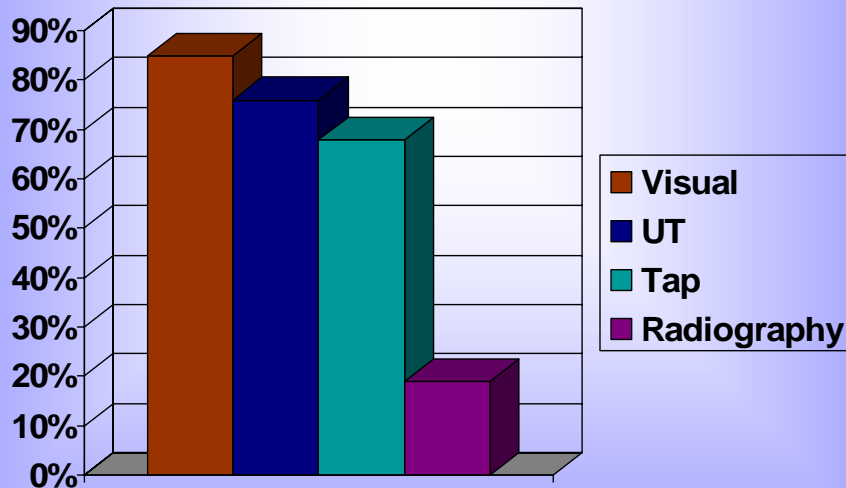
In regards to whether companies have validated accelerated test methods, most neither agreed nor disagreed

Most responses indicated that critical defect locations and types identified are based on a mix of the following:



Product Development, Substantiation and Support

Based on responses, the procedures used to inspect bonded structure and repairs in the field are split between Visual (85%), UT(76%), Tap(68%) and Radiography (19%)



Most respondents said that inspection was important to the maintenance of bonded structures

Most companies agreed that its service experience with bonded structures and or repairs has been good and that these experiences have been application dependent

Responses show that the most common damages or defects found for bonded structure in the field is split between Moisture Egress (46%) Corrosion (41%) and Impact (32%)

Survey Overview

- NIAR and the FAA sincerely appreciate everyone's effort to complete the survey
- Amount of information obtained from survey is immensely valuable
- NIAR is still reviewing responses to gain additional information from the survey
- The information returned will be continually consulted to get further insight into industry practices, concerns and requirements
- Survey will be documented in an FAA Technical Center draft report late 2004