Process Specification for Adhesive Bonding

Engineering Directorate

Structural Engineering Division

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REVISIONS		
VERSION	CHANGES	DATE
--	Original version	12/95
A	Reformatted entire document to conform to current PRC format. Changed "Class A" and "Class B" to "Level 1" and "Level 2" respectively in accordance with JSC 8500. Removed 1,1,1 Trichloroethane as a cleaning solvent. Removed specific pressure call-outs and referred to material specifications for the correct pressure call-outs.	9/16/97
B	Reviewed per ISO requirements. Removed sentence referring to manufacture of composite parts (Section 6.1)	1/26/2001
C	Removed references to old Division name. Added reference document for surface preparation of plastics that describes corona discharge.	11/5/02
D	Reviewed per QMS requirements. Updated reference document numbers. Added bondline thicknesses.	4/15/2005
E	Expanded hardness testing requirement to all adhesives.	5/29/2009
F	Corrected paragraph references in paragraph 3.2. Spelled out MDS acronym in paragraph 5.2.	6/1/2011
G	Added verification of solvent compatibility for sensitive substrates before use. Added glass beads as a means for bondline control. Revised hardness requirements for Level 2 bonds.	12/10/2019
H	Overall terminology changes throughout the document include NOE to NDE for non-destructive evaluation and MOS to TDS for supplier's material technical data sheet. Added references to AMS 2750, ASTM D2651, ASTM F22, and MSFC-SPEC-445 to Sec 4. Sec 5.2 and Sec 6.2 added wording for awareness with uncured adhesives exposure to temperature. Sec 6.1 includes reference to utilizing material specifications and/or TDS. Added Level 1 and structural bonding contractor requirements for specifications. Sec 6.4.2 added	08/06/2026

	maximum allowance for mismatch of details. Section 6.6 had additional content for more details of surface preparation, care in handling, and water break free evaluation for cleaned surfaces. Sec 6.11 added preference for pyrometry calibration and other details that may impact hardware reaching minimum cure temperature with airflow. Sec 6.12 added purpose of process control testing and optional peel and wedge crack testing. Added recommendation for NDE on Level 1 bond. Sec 8 includes process verification to include cohesive bondline failures. Section 10 added technical data sheet, water break free and cohesive definition	

1.0 SCOPE

This document covers the requirements for the adhesive bonding of metals, plastics, and composites in any combination.

2.0 APPLICABILITY

This specification applies to adhesive bonding associated with space flight or space flight- related hardware fabricated under the authority of the NASA/Johnson Space Center (JSC).

3.0 USAGE

This section gives the requirements for the proper use of this process specification.

In accordance with the drawing and part definition requirements of JSC 8500, "Engineering Drawing System Requirements", the standard adhesive bonding process shall be invoked by providing a process note in the applicable drawing or CAD model as exemplified in Figure 1.

ADHESIVELY BOND PER JSC PRC-1001, LEVEL 1

Figure 1. Example of a process note for adhesive bonding.

3.1 LEVEL

The "Level" designator governs the extent to which quality assurance provisions are applied and shall be specified in the process note on the basis of the following definitions:

a. Level 1 - Level 1 processes shall include the practice of the quality assurance provisions as required by Section 7.1. Whenever invoking these Level 1 provisions, the designer should also consider calling out an NDE process specification on the drawing or CAD model.

b. Level 2 - Level 2 processes shall include the practice of the quality assurance provisions as required by Section 7.2.

3.2 CURE AND POST-CURE SCHEDULES

Unless otherwise stated on the drawing or CAD model, standard cure and post-cure schedules will be applied to the material in accordance with Sections 6.11.1 and 6.11.2. Add special cure or post-cure instructions, if necessary, to the process note on the applicable drawing or CAD model.

3.3 NON-DESTRUCTIVE EVALUATION (NDE)

This specification does not address the application of non-destructive evaluation (NDE) methods. However, when calling for Level 1 processing, the designer should also consider the use of NDE inspection by calling out a separate NDE process specification on the drawing or CAD model.

4.0 APPLICABLE DOCUMENTS

The following documents were used in developing this specification:

JPR 8500.4	*Engineering Drawing System Requirements*
JPR 5322.1	*Contamination Control Requirements Manual*

The following documents are invoked as part of this specification:

AMS 2750	*Pyrometry*
ASTM D 2093	*Standard Recommended Practice for Preparation of Surfaces of Plastics Prior to Adhesive Bonding*
ASTM D 2651	*Standard Recommended Practice for Preparation of Metal Surfaces for Adhesive Bonding*
ASTM D 3933	*Standard Guide for Preparation of Aluminum Surfaces for Structural Adhesives Bonding (Phosphoric Acid Anodizing)*
ASTM D2651	*Standard Guide for Preparation of Metal Surfaces for Adhesive Bonding*
ASTM D 1002	*Strength Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal)*
ASTM F22	*Standard Test Method for Hydrophobic Surface Films by the Water-Break Test*
ISO 13895	*Adhesives - Guidelines for the Surface Preparation of Plastics*
MSFC-SPEC-445	*Adhesive Bonding, Process, and Inspection, Requirements for*

5.0 MATERIAL REQUIREMENTS

5.1 MATERIAL SPECIFICATIONS

All materials used in the adhesive bonding process shall conform to applicable Government or other specifications.

5.2 MATERIAL OUT-TIME AND SHELF-LIFE

Adhesive materials are sensitive to temperature exposure. Review all storage temperatures to ensure adhesive materials are not exposed to temperatures that will degrade their performance.

The out-time and shelf-life of the material shall not exceed the shelf-life requirements specified by an applicable Technical Data Sheet (TDS). Traceable out-time and shelf-life records shall be kept for materials whose TDS specifies out-time and shelf-life limits. If the material out-time or shelf life exceeds the TDS specifications, then a requalification of the material shall be accomplished in a manner prescribed by the TDS.

6.0 PROCESS REQUIREMENTS

6.1 WRITTEN PROCEDURES AND STANDARDS

Adhesive bonding is a special process and needs to have detailed written instructions. Contractors for all Level 1 and other structural adhesive bonds shall create a specification for preparation, processing, inspection, handling, and personnel training of adhesive bonded parts as outlined in MSFC-SPEC-445. Level 2 bonding can identify key parameters for the special process on the engineering drawing and/or contractor specification. All specifications shall be qualified and assess bonding sensitivity.

For work performed at JSC facilities, written procedures shall be used and they shall consist of Detailed Process Instructions (DPI's) selected for use from the DPI-1001- series of work instructions. These instructions shall provide information necessary to create a quality bondline for its application. If applicable, material specifications and TDS shall be used to control the materials and processes in the DPI.

At a minimum, TDS's shall be used internally when a DPI does not exist with authority of an M&P Engineer.

6.2 FACILITIES

All bonding operations shall be performed in a controlled environment that is free of contaminants to the extent that bonding operations are not affected. The bonding environment shall have controlled temperature and humidity as required to prevent degradation of the adhesive bond. Please review the TDS to identify appropriate environmental conditions for adhesives.

6.3 MASKING

Parts and assemblies shall be masked as necessary to protect surfaces not to be bonded from damage, contamination from adhesives, cleaning solutions, or abrasives.

6.4 PREFIT OF PARTS

All detail parts shall be free from burrs, waves, and other imperfections. The detail parts shall provide adequate contact over the entire bonding area.

6.4.1 LEVEL 1 REQUIREMENTS

Where practicable, the detail parts shall be prefit to determine mismatch. Surfaces not prefitted shall conform to the applicable drawings. Bonding surfaces which conform to all of the following requirements are exempt from prefit:

a. Both surfaces are nominally flat.

b. Smallest dimension is 2.00 inches (5.00 cm) or less.

c. Total bonding surface area is less than 8.00 square inches (51.6 cm2).

Mismatch between detail parts shall not exceed the requirements of Table I.

Table I. Mismatch Requirements

Adhesive Type	Mismatch	% of Bonding Area Allowed	Layers to Use
Film	1 Thickness Layer	**NA**	1
	Between 1 and 2 Thickness Layers	5	2[a]
	Between 2 and 3 Thickness Layers	5	3[a,b]
	4 Thickness Layers	0	Rework Parts
Paste	0.000" - 0.005"	100	NA
	0.005" - 0.015"	5	NA
	>0.015"	0	NA

NOTES:
a. Gaps or butt splices are not permitted in the adhesive film. Overlaps in the adhesive film up to 0.125 inch (0.318 cm) are permissible.
b. Where multiple layers of adhesive are used in a bondline, successive layers shall be stepped approximately 0.25 inch (0.64 cm) (except along the edge of a detail) to fair the bondline.
c. NA Not Applicable

6.4.2 LEVEL 2 REQUIREMENTS

The detail parts shall be prefitted prior to bonding to assure non-interference conditions. The mismatch of bonding surface should not be greater than the overall desired bondline for type of adhesive.

6.5 SURFACE CLEANING

The detail parts shall be precleaned to remove oil, greases, inks, etc. using either methyl ethyl ketone (MEK) or isopropanol in the case of metals. Caution is to be taken when identifying the appropriate maximum impurities allowed in cleaning solvents. For critical bonding, it may be necessary to utilize a solvent that is reagent grade or even ultra-pure.

Isopropanol or acetone is acceptable with thermoplastics, thermosets, paints, coatings, etc. which are not compatible with MEK. If isopropanol and acetone affect the substrate, degreasing solvents shall be verified to be compatible with the substrate before use. Silicone based cutting and forming fluids shall not be used when processing detail parts for bonded assemblies.

An alkaline cleaner may be necessary to properly degrease the surface of the hardware. ASTM D2651 and ASTM D2093 describe recommended practices for cleaning methods on metallic and non-metallic surfaces. Surfaces shall ensure all residual cleaning agents are removed prior to bonding. Adhesion will be affected by any chemicals, fingerprints, or soils left behind on the surface. Water break free surface is a good method to visually determine if contaminants have been removed from the bonding area. Handling of hardware after cleaning shall be with approved gloves for the chemicals being used in order to prevent glove residual extraction and further contaminating the bonding area with grease from hands.

6.6 SURFACE PREPARATION

6.6.1 PLASTIC SURFACES

Plastic surfaces shall be prepared for adhesive bonding per ASTM D 2093.

6.6.2 METALLIC SURFACES

Metallic surfaces shall be prepared for adhesive bonding per ASTM-D2651, in general, and per ASTM D 3933 for phosphoric acid anodizing of aluminum.

The maximum elapsed time between surface priming and the application of adhesive for metallic parts shall be 12 hours. The time lapse is dependent on the type of surface pretreatment being conducted and should be evaluated for the specific application. For example, titanium surfaces can easily create a natural oxide on the surface and should be primed as quickly as possible.

NOTE: Other surface preparation methods are available but not currently qualified per PRC-1001. Sol-gel applications are commonly found within the industry and require their own process specification for application.

6.6.3 UNPRIMED SURFACES

Unprimed surfaces shall not be solvent-wiped subsequent to surface preparation and before priming or assembly for adhesive bonding.

6.7 PRIMER APPLICATION

When an adhesive primer is specified on the design drawing, the primer shall be applied to the prepared surfaces to be bonded. The time between surface preparation and primer application, the primer thickness, the primer cure, and the maximum time between primer cure and adhesive application shall be in accordance with the applicable material specification or the manufacturer's recommendation for those materials when a material specification does not exist.

6.8 ADHESIVE APPLICATION

6.8.1 FILM ADHESIVES

Unless otherwise noted on the drawing, or in accordance with mismatch requirements of Table I, one layer of film adhesive shall be applied between faying surfaces. Pressurization and cure of the adhesive shall begin within the out-time of the adhesive.

6.8.2 PASTE ADHESIVES

The adhesive components shall be mixed in accordance with the adhesive technical data sheet (TDS), or the manufacturer's recommendations for those materials when a material specification does not exist. The adhesive shall be applied to both faying surfaces. Unless otherwise noted, the adhesive thickness shall be 0.003 - 0.007 inches. Assembly of the parts and pressure application shall take place before the adhesive work-life expires.

6.8.2.1 SCRIM CLOTH

One layer of scrim cloth can be placed between faying surfaces for bondline control when called out on the design drawing. This is only applicable to paste adhesives.

6.8.2.2 GLASS BEADS

Glass beads can be used for bondline control when called out on the design drawing. The concentration of glass beads should be kept at or below 0.5% by weight to avoid stress concentrations within the bondline. This is only applicable to paste adhesives.

6.9 ASSEMBLY OF PARTS

Care shall be taken in assembling parts in the curing fixture or bonding jig to assure that the adhesive is not disturbed during the cure period, and that excessive residual stresses in the components are avoided. Shims, caul plates, and other shop tools shall be used as much as necessary to ensure that every adhesive bondline has adequate support and pressure application.

6.10 PRESSURE APPLICATION

Pressure shall be maintained throughout the cure of the adhesive. When heat is applied to the adhesive to promote cure, pressure may only be removed after the assembly cools to at least 150°F (66°C).

6.10.1 VACUUM BAGS

A minimum of 20 inches Hg (0.068 MPa) is required throughout the cure when using vacuum bags unless otherwise indicated in the material specification or on the drawing.

The vacuum pressure shall be regularly monitored and recorded for Level 1 processes. The vacuum gauge shall be placed at a position remotely away from the inlet to the vacuum pump line.

6.10.2 AUTOCLAVES

Vacuum is initially needed to seat the diaphragm against the bonded assembly. The pressure differential shall be maintained according to the material specification or drawing throughout the cure. The differential pressure shall be regularly monitored and recorded for Level 1 processes.

6.10.3 DEAD WEIGHT

Dead weight pressure is acceptable for relatively flat adherends. The pressure applied shall be according to the material specification or the drawing throughout the cure when using dead weight loading.

6.11 ADHESIVE CURE

The cure and/or post-cure cycle (time, temperature, and pressure) shall be in accordance with the applicable material data sheet, or the manufacturer's recommendation for those materials when a material specification does not exist. Equivalent cure cycles, when specified on the engineering drawing, may be used provided cured adhesive properties are maintained.

Cure time shall commence when the hardware has reached its required minimum temperature. Large tooling or placement in oven may impact the efficiency of the hardware to reach its minimum curing temperature.

6.11.1 APPLICATION OF HEAT

Heat, if needed, shall be applied by the use of either a circulating air oven, an autoclave, heater blankets or heat lamps.

Level1 bonding for spaceflight hardware has preference to use heating devices that have been calibrated to AMS 2750.

6.11.2 TEMPERATURE MEASUREMENTS

Temperature measurements shall be recorded by means of thermocouples. The thermocouple shall be placed in the flash area of the adhesive if possible. Otherwise, a thermocouple placed on the part on the outer mold line of the bond is

acceptable.

6.12 IN-PROCESS VERIFICATION TESTING

Process verification is used to monitor the controls in place for adhesive bonding. With critical process steps required to make a quality cohesive bondline, it is recommended to implement process verification testing. These tests will help evaluate environmental factors, training of personnel, functionality of the equipment, material integrity, and robustness of the process.

In addition, to the required tests identified in Section 6.12.17.0, other testing can be implemented such as wedge crack testing, floating roller peel, and t-peel tests.

6.12.1 LAP SHEAR TESTS

A minimum of five representative lap shear specimens, conforming to ASTM-D-1002, shall be bonded with each application of adhesive, at the same time, with the same adhesive, in the same equipment, and cured under the same conditions for the assembly they represent. The adherend may be a material other than that specified on the design drawing provided that the specimen surfaces are prepared as necessary to achieve bonded specimens that adequately represent the bonding process. If primer and/or scrim cloth and/or glass beads are used in the assembly, then primer and/or scrim cloth and/or glass beads shall be used in the specimens.

6.12.2 HARDNESS TESTS

In addition to the lap shear specimens, a hardness specimen shall be potted for in-process verification of adhesive cure. It shall be cured at the same time, with the same adhesive, in the same equipment, and under the same conditions for the assembly it represents. No vacuum or pressure is required. The specimen shall be removed from the bonding equipment and tested according to section 7.1 prior to pressure/temperature removal.

6.13 RECORDS

Pressure, time, and temperature records on each part shall be recorded at least every 15 minutes. These records shall be retained for permanent reference on each lot of material and on each production part for the life of the part for Level 1 processes.

6.14 WORKMANSHIP

Bonded joints shall be of high-quality workmanship. Acceptable parts shall be free of defects that adversely affect intended use. Appearance shall be uniform and free of defects as specified herein or on the design drawing. Adhesive shall be evident at the edge of all visibly accessible bondlines.

7.0 PRODUCT ACCEPTANCE TESTING

7.1 LEVEL 1 BONDS

Product acceptance shall be based on a test evaluation of the process control test specimens described in section 6.12 that accompany the product. The lap shear specimens shall be tested per ASTM-D-1002 at room temperature. Hardness specimens shall undergo Shore D or Share A hardness evaluation as appropriate for the adhesive used.

For product acceptance, the lap shear strengths and hardness results shall meet or exceed the design allowables of the adhesive. If design allowables are not available, vendor-provided allowables (S allowables) with an applied factor of safety are permissible. This factor of safety shall be provided by the engineering organization responsible for process engineering.

Level 1 bonding will generally have NDE inspection criteria to ensure full coverage of the bondline.

The results of product acceptance testing shall be recorded.

7.2 LEVEL 2 BONDS

Product acceptance shall be based upon a visual inspection of the product and a test evaluation of a potted adhesive hardness specimen. Visual inspection shall address bondline uniformity and cure of the adhesive. The hardness specimen shall be as described in section 6.12.2 and shall undergo Shore D or Shore A hardness evaluation as appropriate for the adhesive used.

For product acceptance, the hardness results shall meet or exceed an allowable for the adhesive. If an adequate allowable is not available, vendor-provided allowables (S allowables) are permissible.

Lap shear test specimens and process verification records are not required.

8.0 PROCESS QUALIFICATION

Detailed process instructions (DPI's) for the bonding process shall be qualified for each combination of materials used prior to acceptance of finished products. Qualification shall consist of documented test evidence that the procedure for bonding, when performed by suitably trained and proficient operators, is capable of meeting all the requirements of this specification. Any change in procedure or materials shall require requalification.

The qualification testing shall involve a minimum of ten lap shear specimens tested at room temperature to qualify the procedure against strength allowables. If adequate allowables are not available, vendor-provided allowables (S allowables) with an applied factor of safety are permissible. This factor of safety shall be provided by the engineering organization responsible for process qualification. Detailed process instructions shall identify key process steps to ensure a cohesive bond failure. Cohesive failures will have fracture within the adhesive bondline and separation of the adhesive is not at the metal interface. Remanent adhesive will remain on both adherends.

9.0 TRAINING AND CERTIFICATION OF PERSONNEL

Training of all bonding technicians shall be performed according to written detailed procedures. Proper training shall, at a minimum, be structured in such a way as to ensure that each trainee is capable of producing adhesive bonds that pass Level 1 process verification criteria. Training and certification records shall be kept.

10.0 DEFINITIONS

a. Faying Surfaces. Pre-bonded, close-fitting surfaces

b. Cohesive Failure. Adhesive fracture occurs internally within the adhesive layer itself, leaving adhesive residue on both sides of the separated metal substrates.

c. Technical Data Sheet. Documentation published by material suppliers that outlines key processing and performance attributes such as storage requirements, shelf life, out time tracking, surface preparation and curing requirements key to provide a quality end item.

d. Water Break Free. Surface allows water to spread into a smooth, unbroken sheet without pulling apart or forming droplets. Reference ASTM F22 for further details.