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# Development of image-based high strain rate tests for adhesively bonded joints

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**14. ABSTRACT**

- A post-doctoral researcher, Dr Vinay Shekar, has been successfully hired and established in Southampton. He has a background in blast/impact. He did his PhD inthe group led by Prof. Gerald Nurick at the University of Cape Town.
- Dr Shekar was trained on the many aspects of the projects he needed to master: understanding the Virtual Fields Method and its application to inertial tests; understanding the Matlab code use to process the data, and adapting it to bonded joints; learning how to run parametric models in Abaqus explicit for the finite element sweeps; Health and Safety training in the lab, and training on the gas gun.
- A brief literature survey on high strain rate testing of adhesives and bonded joints was undertaken by Dr Shekhar.
- Two adhesive systems were identified and sourced after consultation with, on the one side, Vipul Ranatunga (AFRL, Dayton OH) and on the other, Joe Shaefer and Brian Justusson from Boeing. A bulk adhesive, Loctite EA9394 and Solvay's FM-300 tape adhesive were selected. Manufacturing routes for both bulk adhesive and bonded joint specimens were set in place, using vacuum to avoid porosities. Good quality specimens were obtained for the bulk EA9394 adhesive and for the bonded joints. Aluminium was selected as the substrate for the bonded joints, and brass was used for the waveguides and impactors as it matched better the average wavespeed in the tested specimens. Testing the tape adhesive was abandoned because of the very small bondlines it created which would have needed more research to find a suitable data processing approach. The tests were replaced by solid bulk adhesive specimens to have a reference for the mechanical properties to check against for the bonded joints tests.
- Four bulk adhesive specimens were tested in the IBII configuration and very consistent stiffness values were obtained, showing a 20% dynamic amplification factor on both Young's and shear moduli (compared to existing data on this adhesive from the literature), for strain rates on the order of 500 s-1 . It has not been possible to spall the specimens as significant non-linear behaviour in compression was observed at the impact edge, limiting the peak stress that could be transmitted after wave reflection. Yield started in compression at about 22 MPa and 0.4% strain.
- Six adhesively bonded specimens were tested in the IBII configuration, showing appropriate strain localisation in the bondline, first in compression, then in tension leading to tensile fracture (spalling). Because of the geometry of the bondline, plane strain conditions were observed so that the stress state was not uniaxial but biaxial. Initial stiffness values were found consistent with that of the bulk material, though maybe a bit lower but more in-depth data processing is required. More data processing is also needed to derive the tensile strength.

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# Final report on Grant FA8655-20-1-7014

# *Development of image-based high strain rate tests for adhesively bonded joints*

European Office of Aerospace Research and Development (EOARD)

Principal investigator: Professor Fabrice Pierron
Post-doctoral researcher: Dr Vinay Shekar

Date: Friday January 12$^{nd}$ 2024

## 1. Introduction

This project aims at exploring news ways of testing adhesives and adhesive joints at high rates of strain. In particular, the project focuses on elastic moduli, as well as strength in tension and combined tension/shear. It is well known that such properties are difficult to measure using Kolsky bars because of the relatively low wave speeds and low strains to failure, preventing quasi-static equilibrium to be achieved before failure. As a consequence, reliable data in the literature only span up to a few 10s of $s^{-1}$.

In opposition to this, the present approach aims at taking advantage of the inertial effects as acceleration fields, derived from full-field time-resolved displacement measurements, can be used as a volume-distributed load cell. This first seminal idea was published in 2011 [1] for a purely elastic loading. It was further progressed through the use of purely inertial loadings [2, 3] and the present project aims at extending the idea to the properties of adhesives. Preliminary results on adhesives were obtained during the final year project of an undergraduate student in 2018, and can be consulted on this online presentation.

Researchers associated to the project:

- Dr Vinay Shekar, post-doctoral researcher at the University of Southampton, funded by the current project.
- Dr Lloyd Fletcher, Lecturer at the University of Southampton until August 2021, now Researcher at UKAEA in Rotherham, not funded by the present project, formerly on the Photodyn programme[1].
- Dr Fabrice Pierron, Professor and PI, formerly funded by the Photodyn programme[1].

Dr Shekhar finished his appointment end of June this year and has now left the university. The one year no cost extension awarded to this project means that the final report will be provided next year at the closure of the project.

## 2. Summary of achievements after the second year

- A post-doctoral researcher, Dr Vinay Shekar, has been successfully hired and established in Southampton. He has a background in blast/impact. He did his PhD in the group led by Prof. Gerald Nurick at the University of Cape Town.
- Dr Shekar was trained on the many aspects of the projects he needed to master: understanding the Virtual Fields Method and its application to inertial tests; understanding the Matlab code use to process the data, and adapting it to bonded joints; learning how to run parametric models in Abaqus explicit for the finite element sweeps; Health and Safety training in the lab, and training on the gas gun.
- A brief literature survey on high strain rate testing of adhesives and bonded joints was undertaken by Dr Shekhar.
- Two adhesive systems were identified and sourced after consultation with, on the one side, Vipul Ranatunga (AFRL, Dayton OH) and on the other, Joe Shaefer and Brian Justusson from Boeing. A bulk adhesive, Loctite EA9394 and Solvay's FM-300 tape adhesive were selected.

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[1] https://photodyn.org

- Manufacturing routes for both bulk adhesive and bonded joint specimens were set in place, using vacuum to avoid porosities. Good quality specimens were obtained for the bulk EA9394 adhesive and for the bonded joints. Aluminium was selected as the substrate for the bonded joints, and brass was used for the waveguides and impactors as it matched better the average wavespeed in the tested specimens. Testing the tape adhesive was abandoned because of the very small bondlines it created which would have needed more research to find a suitable data processing approach. The tests were replaced by solid bulk adhesive specimens to have a reference for the mechanical properties to check against for the bonded joints tests.
- Four bulk adhesive specimens were tested in the IBII configuration and very consistent stiffness values were obtained, showing a 20% dynamic amplification factor on both Young's and shear moduli (compared to existing data on this adhesive from the literature), for strain rates on the order of 500 $s^{-1}$. It has not been possible to spall the specimens as significant non-linear behaviour in compression was observed at the impact edge, limiting the peak stress that could be transmitted after wave reflection. Yield started in compression at about 22 MPa and 0.4% strain.
- Six adhesively bonded specimens were tested in the IBII configuration, showing appropriate strain localisation in the bondline, first in compression, then in tension leading to tensile fracture (spalling). Because of the geometry of the bondline, plane strain conditions were observed so that the stress state was not uniaxial but biaxial. Initial stiffness values were found consistent with that of the bulk material, though maybe a bit lower but more in-depth data processing is required. More data processing is also needed to derive the tensile strength.

## 3. Methodology

The methodology employed for this project involves both numerical and experimental tools. Progress is briefly summarized for each work package.

### *Work package 1: IBII tests*

*WP1.1. Design sweeps to determine optimal test geometries for the IBII test. This is based on explicit FE simulated data to feed into the VFM approach. Dominant tensile and shear properties will be addressed separately, as well as coupled tension/shear by using off-axis (inclined) bondlines. Strain rates in the 1000s /s can be achieved with this.*

The finite element sweeps have been run and have identified the need to use projectiles and waveguides made from brass to better match the wave speed of the adhesive. The Matlab code developed as part of the PhotoDyn project [4] has been adapted to the situation of bonded joints and used to process the data. The initial set of results showed that impactors of lengths between 30 and 40 mm lead to the required concentration of tensile stress to fracture the specimens. However, in the simulations, the alignment is perfect so that the stress distribution is symmetrical with respect to the specimen axis. This causes concern that the so-called 'Linear Stress Gauge' equation [5] may not approximate the stress at failure very well. We have therefore introduced a slight in-plane misalignment of the impactor to produce shear waves and this made the use of the so-called 'generalized stress-strain curves' possible. As a result, we decided to abandon the option of inclined bondlines, but replaced this with the idea of a half-height impact, as proposed in [6]. This showed promise but it was decided to stick with the slightly misaligned full-height configuration for the experimental tests.

*WP1.2. Detailed optimisation of the most promising test configuration(s). Use of identification simulator developed in [7, 8] to realistically evaluate identification performance. This will need to implement cohesive elements to simulate fracture, which is a novelty here.*

The simulator (synthetic image deformation, see [9] for instance) was used to explore the effects of noise and data processing parameters (spatial and temporal smoothing kernels) on the identified stiffness components. Because of the small area occupied by the bondline, it was found that optimal parameters tended towards no spatial smoothing (as this would smear out the strains between the adhesive and the substrate) and some temporal smoothing (typically over a kernel of 11 to 21 images). As a consequence of the strong constraint of no spatial smoothing to curb the systematic error, it was found that the data were much noisier than for a standard IBII test.

The other strong conclusion was that the standard IBII processing was only possible for bondlines of at least 1.5 mm thickness with the current camera spatial resolution (Shimadzu HPV-X, 400 x 250 pixels). Below this, there is not enough spatial resolution to properly calculate the strain in the adhesive and the systematic error shoots up. We have explored several alternatives to the standard IBII test processing: taking the displacement on each side of the adhesive to calculate an average strain, or using a finite element assisted process where the systematic error would be evaluated from an image deformation study and the experimental data corrected for it. Both led to rather unsatisfactory results and we decided to focus on a 2 mm adhesive bondline in the experiments, using the bulk adhesive (Loctite EA9394).

*WP1.3. Experimental implementation: study of different specimen configurations on a couple of adhesive systems.*

Two adhesives were selected after consultation with colleagues at AFRL and Boeing. The first one is a bulk two-part epoxy adhesive, Loctite Hysol EA9394, and the second is an epoxy-based tape adhesive from Solvay, FM-300. The selected substrate is an aerospace grade aluminium 6061 T6 of thickness 4 mm. Because of the results from WP1.2 and lack of time, it was decided to set aside the tape adhesive and focus on the bulk adhesive. However, these tests were replaced by bulk adhesive testing so that a reference set of properties are available to compare with the bonded joint tests.

WP1.3.1 Bulk adhesive testing

It was decided to first test the EA9394 adhesive in bulk form to obtain reference values for the stiffness and failure stress. The initial batch of specimens suffered from large pores and the manufacturing process had to be revised. It is now satisfactory; a set of six specimens were made that bear no trace of macro-porosities. A sacrificial specimen was sliced to check for such pores and none were found. The six specimens have been grid printed using a flatbed printer and tested at speeds varying from 30 to 50 m.s$^{-1}$. Following the sweep in WP 1.1 and the fine tune in WP 1.2, the brass impactors and wave-guides have been machined to dimensions and the tests have been performed on 6 specimens, from which four proved valid. Indeed, there was some instability in the triggering that we had not seen before, and following this, the Arduino-based triggering system was updated to trigger off the first contact point of the four bits of copper tape bonded to the waveguide. This stabilized the triggering for the adhesive tests, leading to the four successful tests.

An attempt was made to make bulk specimens from the tape adhesive but the resin proved too fluid. We have decided to abandon this task since the validity of the approach can be proved using EA9394 so the bulk FM300 specimens are not essential.

The data were processed using the standard IBII test method. Using the uniaxial stress gauge equation (neglecting the transverse stress component, Eq. 2 in [10]), Young's modulus values were obtained. Using the shear stress gauge equation (Eq. (3) in [10]), using the fact that small impact misalignments produced some levels of shear, shear modulus values were identified. The results are provided in Table 1, together with quasi-static values at 25°C obtained from the adhesive technical datasheet (in appendix to this document) and tests published by Sandia.

Table 1 – Stiffness from IBII tests on bulk adhesive (Loctite EA9394). Strain rate ~500 $s^{-1}$.

| | Impact speed ($m.s^{-1}$) | E (GPa) | G (GPa) | $\nu$ (from E and G) |
|---|---|---|---|---|
| Specimen 1 | 29.3 | 5.1 | 1.9 | 0.34 |
| Specimen 2 | 31.8 | 5.1 | 1.8 | 0.42 |
| Specimen 3 | 40.1 | 4.9 | - * | - |
| Specimen 4 | 50.9 | 5.1 | 1.8 | 0.42 |
| **Average** | **-** | **5.05** | **1.83** | **0.39** |
| **Quasi-static(1)** | | **4.24** | **1.46** | **0.45** |
| **Quasi-static(2)** | | **4.20** | | **0.40** |
| **Dynamic/static** | | **1.19** | **1.26** | **0.87** |

*: not enough shear for a meaningful value of G. (1) Loctite datasheet. (2) T.R. Guess, E.D. Reedy, M.E. Stavig, Mechanical properties of Hysol EA-9394 structural adhesive, Sandia National Laboratories report SAND95-0229, 1995.

Looking at the stress-strain curves (see Figure 1), it is clear that non-linearity of the adhesive is reached at about 0.4% strain (and about 22 MPa of stress). This is consistent with data in T.R. Guess, E.D. Reedy, M.E. Stavig, 1995 (see reference above).

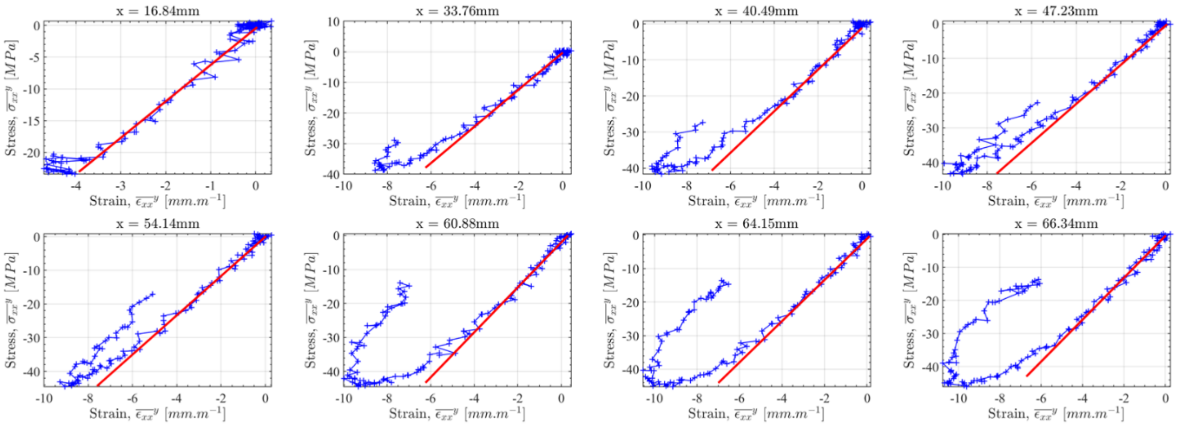

Figure 1 – Stress-strain curves for specimen 1 at different sections along the length (x = 0 corresponds to the specimen free edge).

Because of this non-linearity, tensile failure (spalling) could not be achieved, even though we tried increasing the impact speed (see Table 1). No compression failure was recorded, even at the highest speed.

As a perspective, it would be interesting to apply the plasticity-VFM as published in [9, 11] to identify a plasticity model.

WP1.3.1 Adhesive joints testing

Bonded joints have then been manufactured with EA9394. However, those also suffered from large pores so the fixture was modified to allow vacuum to be applied during cure. Six specimens were then manufactured, with a bondline of 2 mm and aluminium substrates.

The FM300 tape requires a cure temperature of 180°C so a dedicated fixture was designed to cure them in an oven with a vacuum, even though we later decided to cancel testing that adhesive because of lack of time.

The six specimens of Al/EA9394/Al (dimensions 70 x 40 x 4 mm$^3$, with a bondline of 2 mm located about two-thirds towards the free edge) were tested at speeds between 40 and 70 m.s$^{-1}$, with brass waveguide and impactor. Figure 2 below shows unfiltered strains and strain rates at two particular times. The first one corresponds to the compressive wave in the adhesive. The second, to the onset of tensile failure after wave reflection. Several things can be noted on these maps. First, the strains are very noisy in the aluminium as strain levels are very low there. These strain maps have not been smoothed spatially (strains were just obtained by centred finite difference from the displacements as this was recommended from the study in WP1.2), hence the low signal to noise ratio in the aluminium. If the properties of aluminium had to be extracted, spatial smoothing would be required (as in [9, 11] for instance). The localisation of the strain in the adhesive bondline is obvious on the $\varepsilon_{xx}$ map. Interestingly, it is not accompanied by a tensile strain in the $\varepsilon_{yy}$ component. This is because the bondline is narrow and wide vertically, leading to conditions close to plane strain with the vertical axis the plane strain axis. As a consequence, transverse stress $\sigma_{yy}$ will be present so that $\sigma_{yy} = \nu\ \sigma_{xx}$ (resulting from writing that $\varepsilon_{yy} = 0$). The constitutive relation therefore yields $\sigma_{xx} = Q_{xx}\ \varepsilon_{xx}$ so that the 'uniaxial stress gauge' equation yields $Q_{xx}$ here instead of E for the bulk adhesive.
The results are still being processed but initial values for $Q_{xx}$ range between 5 and 6 GPa, so consistent with that in Table 1 but more refined analysis needs to be performed. The same yields for the tensile strength for which the so-called 'linear stress gauge' approach will be used (see [5]).

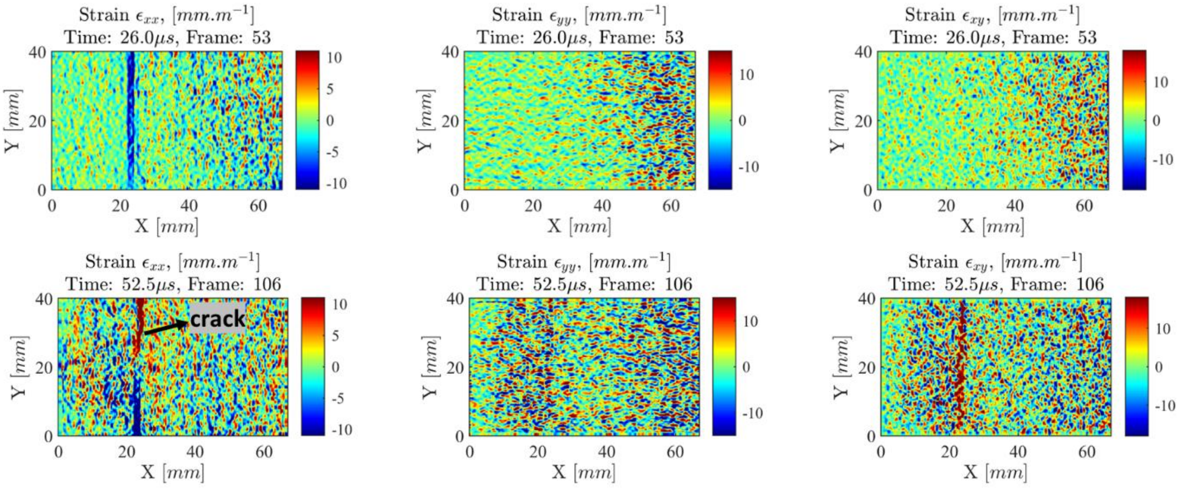

Figure 2 – Unfiltered strain maps at 26 and 52.5 $\mu$s for an aluminium/EA9394/aluminium specimen

***Work package 2: IBUS tests***

This WP has been abandoned altogether following the difficulties in data processing encountered in WP1 and the delays associated with the Covid crisis early 2021 (see below).

*WP2.1. Design sweep to determine optimal test geometries for the IBUS test. This is based on FE simulated data to feed into the VFM approach. Dominant tensile and shear properties will be addressed separately, as well as coupled tension/shear by using off-axis (inclined) bondlines. Strain rates in the 10s to 100s /s can be achieved with this.*

*WP2.2. Detailed optimisation of the most promising test configuration(s). Use of identification simulator developed in [7, 8] to realistically evaluate identification performance. This will need to implement cohesive elements to simulate fracture, which is a novelty here.*

*WP2.3. Exploration of using the 'jumping height' as a first approximation of the fracture toughness. Strain rates in the 100s /s can be achieved with this.*

*WP2.4. Experimental implementation: study of different specimen configurations on a couple of adhesive systems.*

## 4. COVID impact

Dr Shekar arrived in the UK mid-January 2021 at the heart of the Covid pandemic. His start on the project was significantly impacted by the situation as the laboratory could not be accessed and he could not enjoy the physical environment of the other researchers in the group. We were granted a one year no-cost extension, which allowed Dr Shekhar to complete his contract end of June 2022. Unfortunately, this was not enough to fully complete the research. In particular, there was not enough time to complete the data processing and write up the journal article. I was ready to offer an extra three months on my reserves but this was not possible due to extra administrative burden imposed now on overseas researchers from certain countries (ATAS, now necessary for South African post-doctoral researchers, a new feature).

## 5. Future work

Future work is limited by the fact that Dr Shekhar's contract has now finished. I will try to find a student to help me complete the data processing with the objective to publish a journal article. In particular, these are the outstanding tasks.

- Process the adhesive joint tests to obtain stiffness parameters and compare with the bulk adhesive data.
- Process the adhesive joint tests to identify the fracture stress using the so-called 'linear stress gauge' approach [5].
- Write a first journal paper on the validation of the IBII test for adhesives using the EA9394 data.

## 6. Publications

None so far (see Covid statement). I have all the data and am planning to write up a journal paper to be submitted to SEM's Dynamic Behaviour of Materials journal, once additional data processing is complete (see Section 5 above).

## 7. Collaborations and impact

- Dr Vipul Ranatunga from AFRL in Dayton, OH, has expressed interest in the work. He has brought in two collaborators from Boeing, Dr Joseph Shaefer and Dr Brian Justusson. A joint online brainstorm meeting led to the selection of the two adhesives for the programme.
- Solvay UK is very interested in the work and have provided adhesive FM300 for free to support the project.

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# APPENDIX 1

## Technical data sheet of HENKEL LOCTITE EA9394

Technical Process Bulletin

# LOCTITE EA 9394 AERO

## Epoxy Paste Adhesive

**(KNOWN AS Hysol EA 9394)**

## INTRODUCTION

LOCTITE EA 9394 AERO is a two-part structural paste adhesive, which cures at room temperature and possesses excellent strength to 350°F/177°C and higher. Its thixotropic nature and excellent high temperature compressive strength also make it ideal for potting, filling and liquid shim applications. LOCTITE EA 9394 AERO is qualified to MMM-A-132 Rev A, Type I, Class 3.

The mechanical properties in this data sheet are also valid for LOCTITE EA 9394S AERO. LOCTITE EA 9394S AERO is only available in Semkits and differs from LOCTITE EA 9394 AERO as it has 1 part less thixotrope in the Part B to aid packaging. All other mechanical and handling properties similar.

## FEATURES

- Room Temperature Cure
- Good Gap Filling Capabilities
- 350°F/177°C Performance
- Potting Material
- Room Temperature Storage
- Outstanding Mechanical Properties
- Long Pot Life
- Low Toxicity

### Uncured Properties

| | Part A | Part B | Mixed |
|---|---|---|---|
| Color | Gray | Black | Gray |
| Viscosity, 77°F<br>Brookfield, HBT | 4000-8000 Poise<br>Spdl 7 @ 20 rpm | 200-700 Poise<br>Spdl 4 @ 20 rpm | 1600 Poise<br>Spdl 5 @ 20 rpm |
| Viscosity, 25°C<br>Brookfield, HBT | 400-800 Pa·S<br>Spdl 7 @ 2.09 rad/sec | 20-70 Pa·S<br>Spdl 4 @ 2.09 rad/sec | 160 Pa·S<br>Spdl 5 @ 2.09 rad/sec |
| Density (g/ml) | 1.50 | 1.00 | 1.36 |
| Shelf Life<br>@ <77°F/25°C | 1 year | 1 year | |

This material will normally be shipped at ambient conditions, which will not alter our standard warranty, provided that the material is placed into its intended storage upon receipt. Premium shipment is available upon request.

## Handling

**Mixing** - This product requires mixing two components together just prior to application to the parts to be bonded. Complete mixing is necessary. The temperature of the separate components prior to mixing is not critical, but should be close to room temperature (77°F/25°C).

| Mix Ratio | Part A | Part B |
|---|---|---|
| By Weight | 100 | 17 |

Note: Volume measurement is not recommended for structural applications unless special precautions are taken to assure proper ratios.

**Pot Life** (450 gram mass) 90 minutes @ 75°F/25°C
Method - ASTM D 2471 in water bath**.**

## Application

**Mixing** - Combine Part A and Part B in the correct ratio and mix thoroughly. THIS IS IMPORTANT! Heat buildup during or after mixing is normal. Do not mix quantities greater than 450 grams as dangerous heat buildup can occur causing uncontrolled decomposition of the mixed adhesive. TOXIC FUMES CAN OCCUR, RESULTING IN PERSONAL INJURY. Mixing smaller quantities will minimize the heat buildup.

**Applying** - Bonding surfaces should be clean, dry and properly prepared. For optimum surface preparation consult the LOCTITE Surface Preparation Guide. The bonded parts should be held in contact until the adhesive is set. Handling strength for this adhesive will occur in 24 hours @ 77°F/25°C, after which the support tooling or pressure used during cure may be removed. Since full bond strength has not yet been attained, load application should be small at this time.

## Dual Cartridge Application

We recommend that you do not precondition the kits, dispense adhesive at ambient temperature. If pre-heating is required for the cartridge kits, do not exceed 90°F for a maximum time of four hours.

- Do not assemble the static mixer onto the cartridge while conditioning.
- Do not place the assembled cartridges upright in the oven.
- Seat kit into the cartridge sleeve/tray and ensure proper placement against the gun plungers. **Misalignment during triggering of the plungers can result in kit damage.**
- Burp the adhesive at **low pressure** prior to dispensing through the static mixer.
    - Allows for both Piston, A & B sides to be equally level during initial dispensing, thus preventing an adhesive backflow.
    - It's possible that the Piston-B Side may be unleveled with the Piston-A side due to the heating & positioning of the cartridge. The Part B resin viscosity is much lower than the Part A resin viscosity 200 ml kit failures will occur if the inlet pressure is set too high while triggering the plungers.
- Start the plungers at **low pressure (20 psi)** then increase to the desired pressure
- Over heating of the cartridge in an oven and then applying high pressure can result in **kit damage and/or resin blowback.**

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- Do not allow the adhesive to sit in the static mixer unattended for more than 90 minutes.
    - The material is curing within the static mixer and when pressure is re-applied back onto the plungers, back pressure will occur and potentially result in cartridge failure.

**Failure to follow the recommended procedures stated in this TDS will void the Warranty of the Adhesive.**

**Note:** Special precautions are recommended to minimize carbonate formation in large assemblies subject to extended open times in humid environments. A special memo is available upon request from Henkel providing users with suggestions for minimizing carbonate formation.

**Curing** - LOCTITE EA 9394 AERO may be cured for 3 to 5 days @ 77°F/25°C to achieve normal performance. Accelerated cures up to 200°F/93°C (for small masses only) may be used as an alternative. For example, 1 hour @ 150°F/66°C will give complete cure**.**

**Cleanup** - It is important to remove excess adhesive from the work area and application equipment before it hardens. Denatured alcohol and many common industrial solvents are suitable for removing uncured adhesive. Consult your supplier's information pertaining to the safe and proper use of solvents.

**Bond Strength Performance**

**Tensile Lap Shear Strength** - tested per ASTM D1002 after curing for 5 days @ 77°F/25°C. Adherends are 2024-T3 bare aluminum treated with phosphoric acid anodized per ASTM D3933.

| | Typical Results | |
|---|---|---|
| Test Temperature, °F/°C | psi | MPa |
| -67/-55 | 3,300 | 22.7 |
| 77/ 25 | 4,200 | 28.9 |
| 180/82 | 3,000 | 20.7 |
| 200/93 | 2,900 | 20.0 |
| 250/121 | 2,300 | 15.8 |
| 300/149 | 1,600 | 11.0 |
| 350/177 | 1,200 | 8.3 |
| 400/204 | 600 | 4.1 |

| **After Exposure to/Test Temperature** | **Typical Results** | |
|---|---|---|
| | **psi** | **MPa** |
| Room Temperature Control (no exposure) | 4,300 | 29.6 |
| 77°F/25°C Water - 7 days @77°F/25°C | 4,100 | 28.2 |
| Isopropyl Alcohol - 7 days @77°F/25°C | 4,000 | 27.6 |
| Hydraulic Oil - 7 days @77°F/25°C | 4,100 | 28.2 |
| JP-4 Fuel - 7 days @ 77°F/25°C | 4,200 | 28.9 |

## Peel Strength

T-Peel strength tested per ASTM D1876 after curing for 5 days @ 77°F/25°C. Adherends are 2024-T3 AlClad aluminum treated with phosphoric acid anodized per ASTM D3933.

| | **Typical Results** | |
|---|---|---|
| **Test Temperature, °F/°C** | **Lb/in** | **N/2 mm** |
| 77/25 | 5 | 22 |

Bell Peel strength tested per ASTM D3167 after curing for 7 days @ 77°F/25°C. Adherends are 2024-T3 AlClad aluminum treated with phosphoric acid anodized per ASTM D3933.

| | **Typical Results** | |
|---|---|---|
| **Test Temperature, °F/°C** | **Lb/in** | **N/25mm** |
| 77/25 | 20 | 89 |

## Service Temperature

Service temperature is defined as that temperature at which this adhesive still retains 1000 psi/6.9 MPa) using test method ASTM D1002 and is 350°F/177°C.

## Bulk Resin Properties

**Tensile Properties -** tested using 0.125 inch/ 3.18 mm castings per ASTM D638.

| | | |
|---|---|---|
| Tensile Strength @ 77°F/25°C | 6,675 psi | 46.0 MPa |
| Tensile Modulus @ 77°F/25°C | 615 ksi | 4,237 MPa |
| Shear Modulus, dry @ 77°F/25°C | 212 ksi | 1,461 MPa |
| Shear Modulus, wet @ 77°F/25°C | 149 ksi | 1,027 MPa |
| Elongation at Break @77°F/25°C | 1.66% | |
| Shore D Hardness, @ 77°F/25°C | 88 | |
| Tg dry | 172°F | 78°C |
| Tg wet | 154°F | 68°C |

**Compressive Properties -** tested with rectangular specimens 0.5 in/12.7 mm width by 1.0 in/25.4 mm length by 0.5 in/12.7 mm height per ASTM D695.

| Compressive Strength, °F/°C | psi | MPa |
|---|---|---|
| 77/25 | 10,000 | 68.9 |

**Electrical Properties -** tested per ASTM D149, D150.

| | 0.1 KHz | 1.0 KHz | 10.0 KHz |
|---|---|---|---|
| Dielectric Constant | 7.72 | 7.51 | 7.20 |
| Dissipation Factor | .017 | .022 | .033 |
| Thermal Conductivity | $7.92 \times 10^{-4}$ cal/sec-cm-°C | | [0.331 W/(m•K)] |
| Volume Resistivity | $4.05 \times 10^{13}$ ohm-cm | | [$4.05 \times 10^{11}$ ohm] |
| Surface Resistivity | $4.60 \times 10^{13}$ ohm | | |
| Coefficient of Thermal Expansion | 55.6µm/m°C @ 40°C<br>80.6µm/m°C @ 100°C | | |

## Handling Precautions

Do not handle or use until the Material Safety Data Sheet has been read and understood.
For industrial use only.

## DISPOSAL INFORMATION

Dispose of spent remover and paint residue per local, state and regional regulations. Refer to HENKEL TECHNOLOGIES MATERIAL SAFETY DATA SHEET for additional disposal information.

## PRECAUTIONARY INFORMATION

### General:

As with most epoxy based systems, use this product with adequate ventilation. Do not get in eyes or on skin. Avoid breathing the vapors. Wash thoroughly with soap and water after handling. Empty containers retain product residue and vapors so obey all precautions when handling empty containers.

# LOCTITE EA 9394 AERO

## Epoxy Paste Adhesive

**(KNOWN AS Hysol EA 9394)**

**PART A**
**CAUTION!** This material may cause eye and skin irritation or allergic dermatitis. It contains epoxy resins.

**PART B**
**WARNING!** This material causes eye and skin irritation or allergic dermatitis. It contains amines.

Before using this product refer to container label and HENKEL TECHNOLOGIES MATERIAL SAFETY DATA SHEET for additional precautionary, handling and first aid information.

**Note**
The data contained herein are furnished for information only and are believed to be reliable. We cannot assume responsibility for the results obtained by others over whose methods we have no control. It is the user's responsibility to determine suitability for the user's purpose of any production methods mentioned herein and to adopt such precautions as may be advisable for the protection of property and of persons against any hazards that may be involved in the handling and use thereof. In light of the foregoing, **Henkel Corporation specifically disclaims all warranties expressed or implied, including warranties of merchantability or fitness for a particular purpose, arising from sale or use of Henkel Corporation's products. Henkel Corporation specifically disclaims any liability for consequential or incidental damages of any kind, including lost profits.** The discussion herein of various processes or compositions is not to be interpreted as representation that they are free from domination of patents owned by others or as a license under any Henkel Corporation patents that may cover such processes or compositions. We recommend that each prospective user test his proposed application before repetitive use, using this data as a guide. This product may be covered by one or more United States or foreign patents or patent applications.

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