THE CRITICAL FACTORS CONTROLLING THE DURABILITY OF BONDED COMPOSITE JOINTS – SURFACE PREPARATION AND THE PRESENCE OR ABSENCE OF PRE-BOND MOISTURE

by

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THE PROBLEM

There are no reliable after-the-fact ways of proving that paint or glue has adhered properly to the underlying surface. Therefore, it is necessary that appropriate process specifications be validated and followed strictly. In the past, this has not always happened! And it is contrary to the culture for riveted structures whereby the full strength *can* be restored by repairs after end-item inspections.

Once a non-bond has been created, it is impossible to detect until a gap opens up or the paint peels off. Worse, the surface at the interfacial failure will remain so slick that local repairs will only hide the weakness without fixing it.

The need for proper surface preparation, such as grit blasting of composite laminates, is not widely appreciated. The absence of pre-bond moisture is just as important as the absence of silicone!

Today's standard QC test, a lap-shear coupon, tells nothing about bond durability for composite structures. On its own, it was equally useless for metal bonding.

OUTLINE

Introduction

Summary of adhesion process

Reliability of grit-blasting

Unreliability of *some* peel plies

Unrecognized adverse effects from pre-bond moisture

Need for durability tests, based on peel loads, to supplement short-term static lap-shear tests that are no more capable of finding "weak" bonds than standard ultrasonic inspections are

Recommendations

Concluding remarks

SUMMARY OF THE ADHESION PROCESS

For glue or paint to “stick”, cleanliness alone is not sufficient.

The polymer must *wet* the substrate.

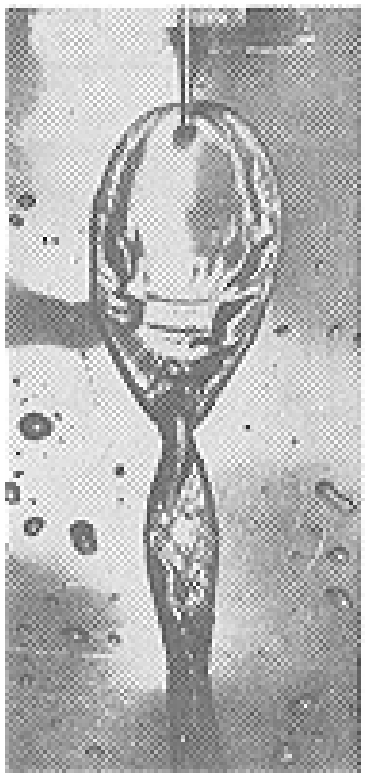
This requires that the surface energy of the adherend be *greater* than that of the polymer. Stronger, stickier glue doesn’t help.

Low-pressure grit blasting removes any inert surface material as well as any contamination.

Peel plies must create a slick surface so that they can be stripped off without damaging the composite part. This is the very antithesis of what is needed for bonding and panting.

The adhesion of epoxy-type polymers is inhibited by even traces of moisture at the interfaces. Laminates must be dried out, and vent paths must be provided for volatiles to escape during cure.

WATER REPELLED BY, AND WETTING, UNTREATED AND “FLAMED” POLYETHELENE PLATES



SOURCE:
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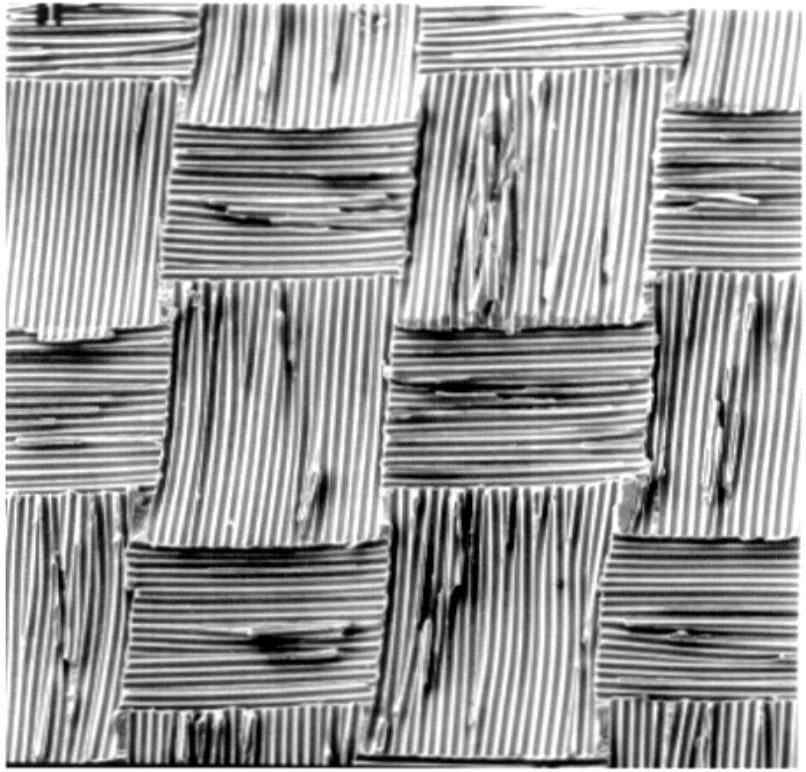
WATER STREAM, FROM TOP, BEADING ON UNTREATED POLYETHELENE PLATE

WATER STREAM, FROM TOP, FLOWING OVER (WETTING) “FLAMED” POLYETHELENE PLATE

CLOSE-UP OF PEEL-PLY IMPRINT SHOWING SLICK TOTALLY INERT BONDING SURFACE



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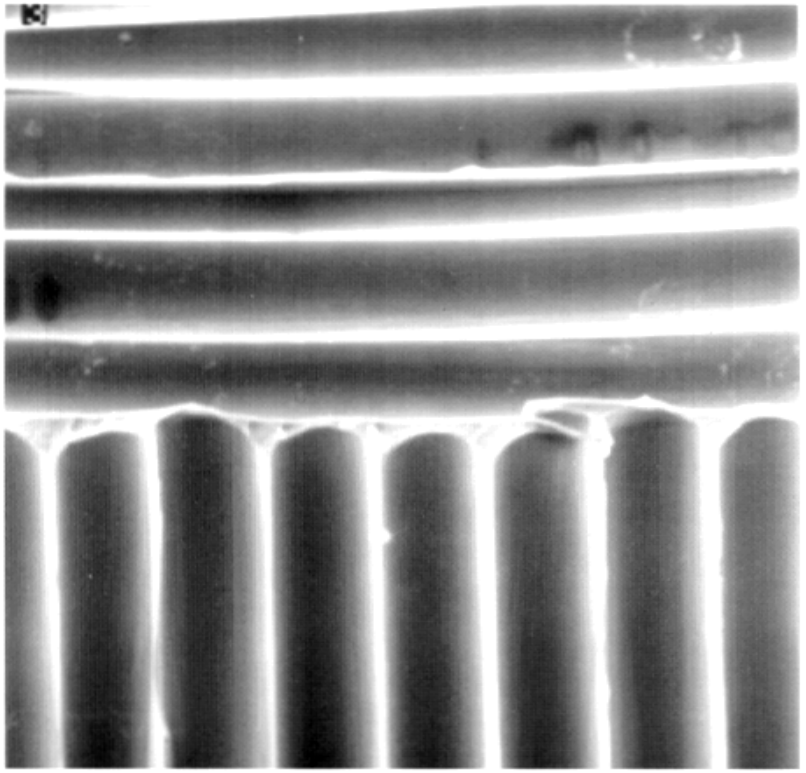

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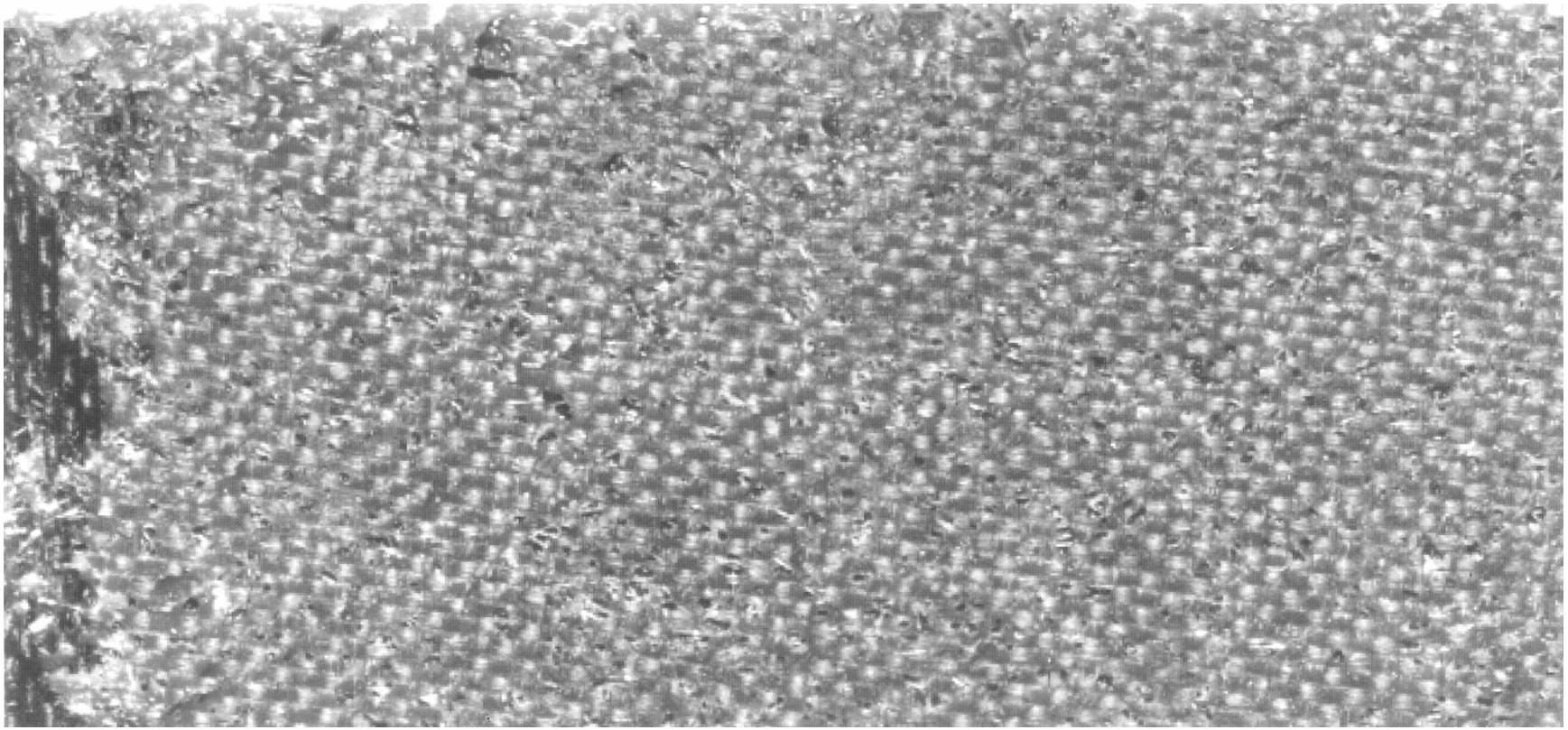
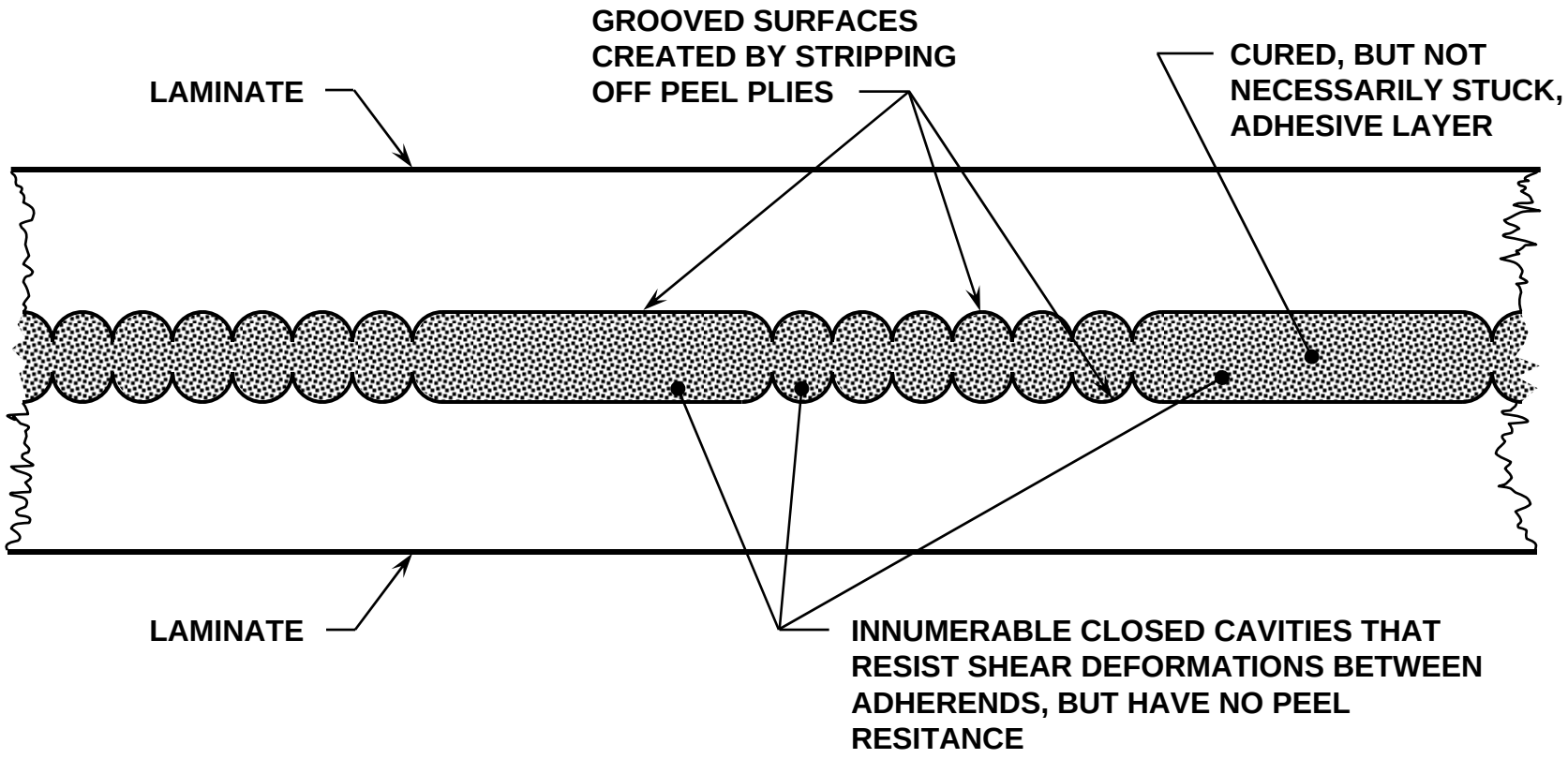
PEEL-PLY IMPRINT LEFT BY FAILURE OF ADHESIVE TO BOND TO A COMPOSITE SURFACE



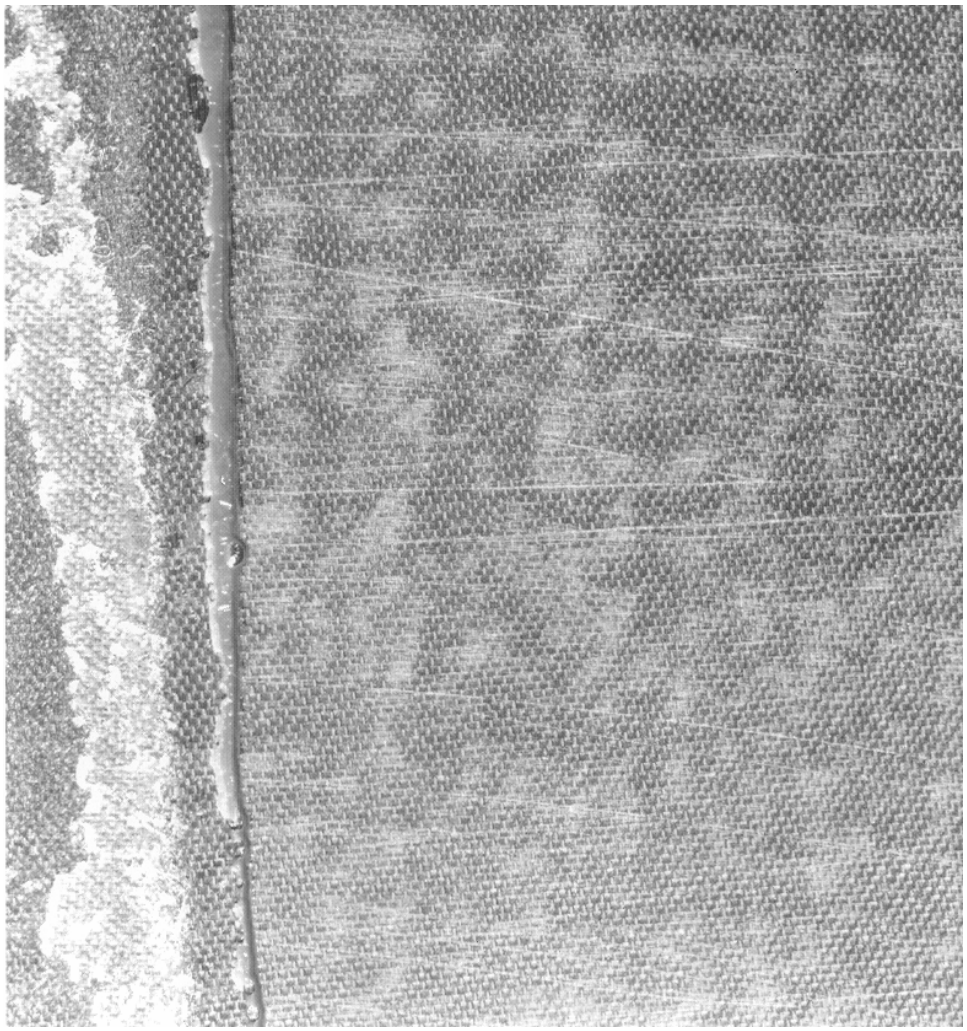
10X

Note clear imprint at left of *other* peel ply in skin underneath adhesive layer, to which the adhesive also failed to bond.

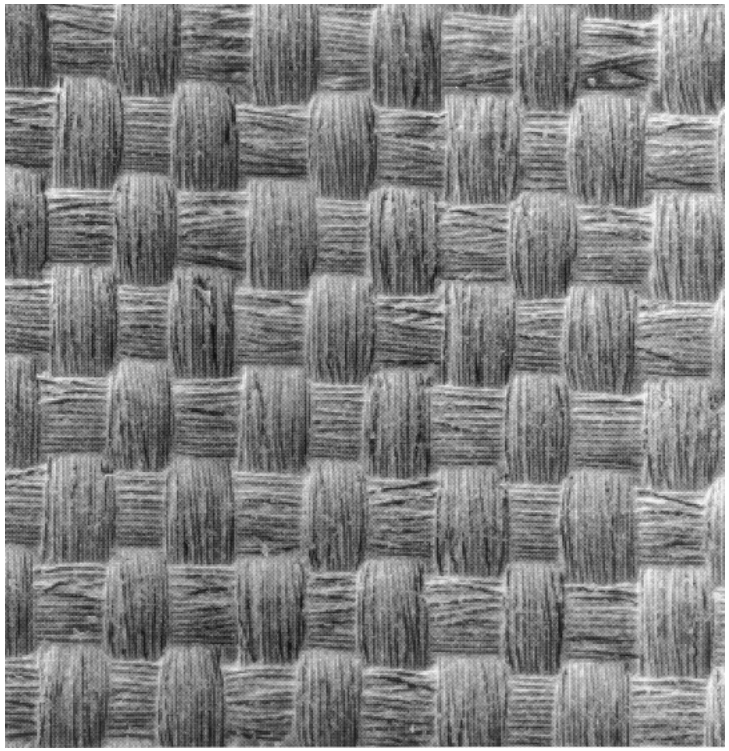
REPRESENTATION OF PEEL-PLY IMPRINT SHOWING ORTHOGONAL SETS OF INTERLOCKING GROOVES



TYPICAL TOTALLY INADEQUATE SCUFF SANDING USED ON COMPOSITE LAMINATES



LIGHTLY GRIT-BLASTED COMPOSITE SURFACE, RETAINING IMPRINT OF PEEL PLY AND SHOWING NO DAMAGE TO UNDERLYING FIBERS



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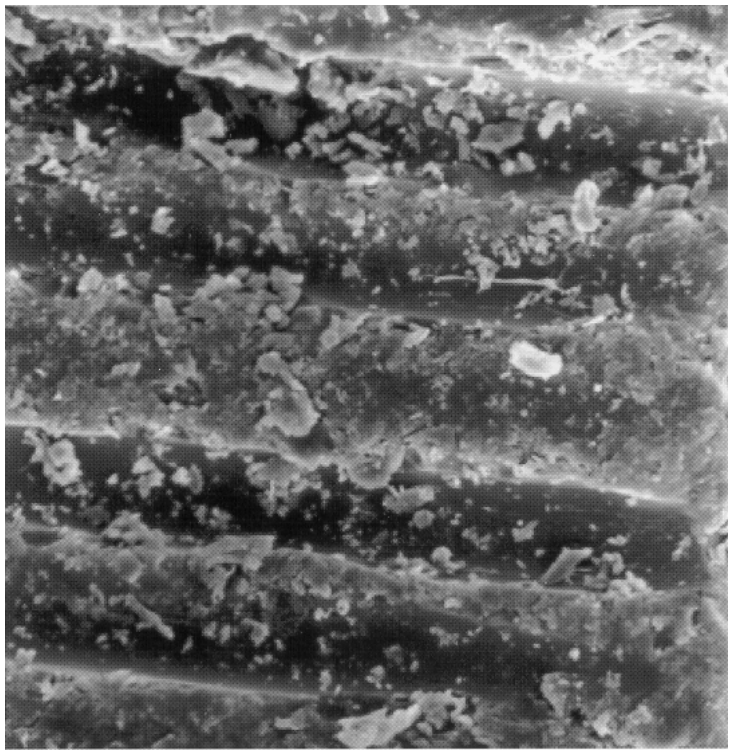

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ANECDOTAL EVIDENCE – 1

Several years ago, there was a problem with paint peeling off the outside of many large composite fairings and revealing the underlying texture of the peel ply laid down to eliminate the need to scrape off release agent transferred from the lay-up tool.

The problem recurred after the parts were repainted.

The problem was solved by grit-blasting the outer surfaces before painting.

However, the bonded inner surfaces that were also created by stripping off the same make of peel plies were not changed.

Why not? Should the adhesive be expected to adhere better than the paint, that obviously didn't?

ANECDOTAL EVIDENCE – 2

At a GA manufacturer, all of Engineering, from the chief engineer down, were convinced of the need to prepare surfaces to be bonded by grit-blasting, based on all the tests they ran with paste adhesives, Which are harder to make stick than heat-cured film adhesives.

Unfortunately, the business plan said it was more cost-effective to hand-sand the surfaces.

However, it was taking hundreds of hours per aircraft to hand-sand the exterior surfaces to achieve an acceptable paint finish.

The business case for grit-blasting the areas to be painted therefore did close, so they bought a grit blaster for that purpose.

Once they had this machine, they were then able to grit-blast the bonding surfaces, too.

ANECDOTAL EVIDENCE – 3

The Lear Fan all-composite aircraft had an essentially all-bonded pressurized fuselage, with rivets in the lap splices that *alone* could not even carry limit load. The surface preparation was excellent, since grit-blasting was mandated throughout.

On the other hand, the tooling concept for bonding the splices left something to be desired, since it repeated a mistake made earlier at the former Douglas Aircraft Company during the PABST program. Rigid external *and* internal tools do not work – some provision is needed to accommodate variations in skin thickness and tolerances in the tool surfaces. Consequently, the splices contained a great many large voids, with only some 50 percent passing inspection.

However, that was more than adequate strength, and none of the voids grew during the hundreds of flights.

More significantly, when NASA Langley used unfinished airframes in crash-worthiness tests in a drop tower, these locally flawed but otherwise sound bonds still didn't fail! The skins tore, instead!

IMPORTANCE OF THE *MODE* OF FAILURE

All bonds known to the author to have failed prematurely in service failed interfacially, because the adhesive had never been stuck. Cohesive bond failures are extremely rare outside the realm of test coupons.

This is a problem, since the non-bond no-gap condition cannot be detected by standard ultrasonic NDI until a gap opens up. Lap-shear QC tests do not reveal non-bonds. Peel QC tests would, but they are not called for. They should be!

The service record of well-bonded structures is excellent, even with the occasional piece of separator ply occasionally left in the lay-up.

In one case there was *zero* disbond *growth* around a 53-square inch Inclusion, after 3½ years of service, which is when it was first detected by visual inspection from some 50 feet away.

CRITICALITY OF PRE-BOND MOISTURE

Silicone on a bond surface, transferred from a released peel ply, is a known problem, and steps are now usually taken to preclude it.

But pre-bond moisture, in or on the adhesive, or absorbed within a pre-cured laminate, is a very under-recognized problem. In reality, is is just as disastrous as silicone contamination. Laminates are very hard to dry, once they have absorbed moisture.

A whole fleet of components was found to have "disbonded" in service because the drying requirements had not been enforced.

In another case, the problem was avoided by an extremely tight limit on the interval between curing and bonding, less than half a day. The production schedule was prepared to accommodate this requirement. Test coupons had failed interfacially at very low loads when there was pre-bond moisture on the adhesive film, so the need for a response was obvious. Even without grit-blasting, this has proved to be a very successful component.

RECOMMENDATIONS

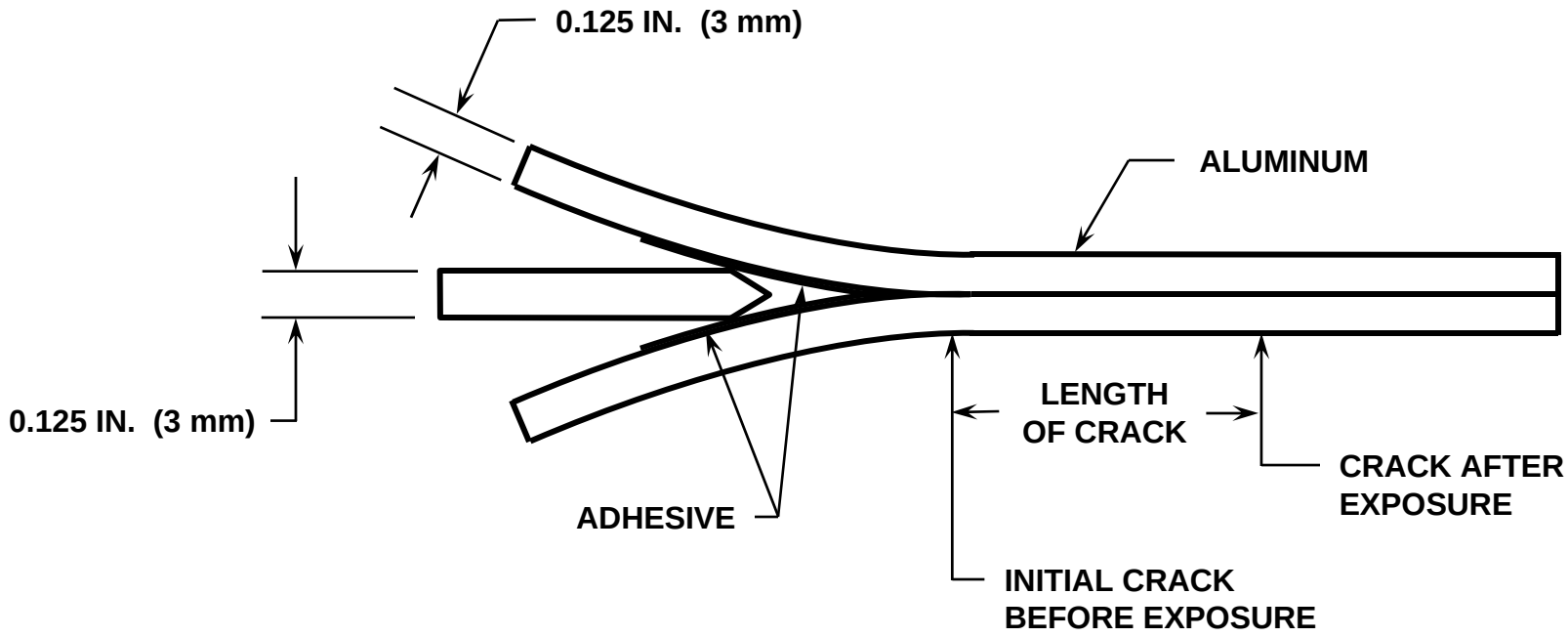
The *mode* of failure for bonded joints must be acknowledged as being even more important than the measured strength.

Interfacial failures must be grounds for rejection, no matter what load was carried or how much of the structure passed ultrasonic inspections.

The QC tests for bonded composite structures *must* be expanded to Include a durability test, the same as or equivalent to the wedge-crack test that restored the integrity of bonded metallic structures.

The process of adhesion needs to be made better known to those in the bonding and painting fraternities, as well as to structures engineers.

BOEING WEDGE-CRACK DURABILITY TEST COUPON



TEST CONDUCTED IN HOT HUMID ENVIRONMENT

CONCLUDING REMARKS

The processes for making paint adhere to the outside of an aircraft and to adhesively bond internal components together are so similar that solutions to problems in one area can help solve problems in the other. The surface needs to be more energetic than the polymer.

It is clear that not all bonding and painting specifications for composites are up to the task. Many need to be rewritten!

There is a strong need for durability testing, equivalent to the wedge-crack test for bonded metal structures, to be *added* to the short-term static lap-shear tests that have proved to be insufficient on their own, to ensure the integrity of bonded composite structures. This should not be surprising, because they were inadequate for bonded metal structures, too.

It is vital that interfacial failures be excluded from tests and products alike, by suitable surface preparations. Tests that apply a peel load, in a hostile environment, are the only known way to do this.

A REMINDER

THE PHYSICS OF THE ADHESION PROCESS WILL ALWAYS OVER-RIDE THE WISHFUL THINKING OF MAN!