Journal of
INDUSTRIAL
TECHNOLOGY

Volume 19, Number 2 - February 2003 to April 2003

Determining if Destructive Testing Can Be Reduced by Using Pre-Yield Strength Data in Analysis of Composite Reinforced Automotive Hood Assemblies

By Mr. Mike Bishop, Dr. Todd C. Waggoner & Dr. Edward C. Kennedy III

KEYWORD SEARCH

Automotive
Composite Materials
Manufacturing
Quality Control
Quality

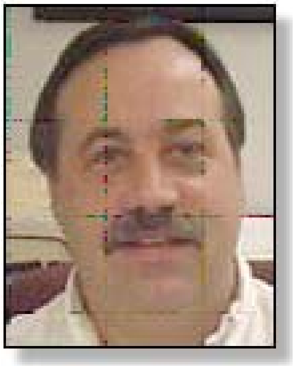
Reviewed Article

The Official Electronic Publication of the National Association of Industrial Technology • www.nait.org

Journal of Industrial Technology • Volume 19, Number 2 • February 2003 to April 2003 • www.nait.org

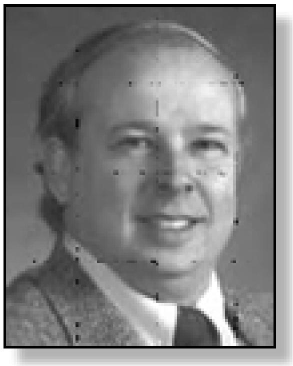
Determining if Destructive Testing Can Be Reduced by Using Pre-Yield Strength Data in Analysis of Composite Reinforced Automotive Hood Assemblies

By Mr. Mike Bishop, Dr. Todd C. Waggoner & Dr. Edward C. Kennedy III



Mike Bishop is a Production Manager and OEM Automotive Supplier. He received his Masters of Industrial Technology in August 2000 from Bowling Green State University. He received his Bachelor of Science in Technology from Bowling Green State University in May 1997. He has 25 years of manufacturing experience with 18 years of automotive supply base experience, primarily in engineering, quality and production management.

Dr. Todd C. Waggoner is an associate professor of Technology Systems in the College of Technology at Bowling Green State University. Todd teaches computer software tools in manufacturing at the doctoral level and concurrent engineering at the master's level. He also teaches metal processing courses, mechanical power, fluid power, and design courses at the undergraduate level.



Dr. Edward C Kennedy III, until August 2002, worked at Bowling Green State University in the Advanced Technological Education (ATE) Program. He is currently an Assistant Professor of Career and Technical Education in the Department of Curriculum and Instruction at the University of Toledo. Ed worked in business and industry for over twenty years before going to academia.

Introduction

The supplier in this study is an automotive original equipment manufacturer (OEM). This supplier produces thermo-set plastic exterior body panels for Chrysler, Ford, and GM. Doors, hoods, deck-lids, and fenders are the typical body panels supplied. The supplier molds outer panels, inner panels, incorporates hardware reinforcements, and bonds the panels together using an epoxy adhesive. The panels are painted with primer, placed in a shipping rack, and then shipped to a specific customer assembly plant.

Replacing Destructive Tests with Pre-yield Strength Data

Conducting expensive destructive tests that indicate the process is in control with no plans for improvement not only violates QS-9000 standards, but also is wasteful and costly. The technical management team's responsibility was to identify sources of waste and submit proposals to reduce it to upper management. One such area was the destructive testing of hood assemblies to verify bond integrity. It was the intent of this study to see if destructive tear-apart tests could be reduced by measuring pre-yield strength of fiberglass reinforced panels and using that as a predictor of the ultimate tensile strength (UTS) they would achieve. If a strong correlation could be drawn between pre-yield strength and UTS some portion of the destructive testing could be eliminated.

The hood assembly bonding system exhibits that the process is in control, but there are a number of issues that must be resolved prior to changing the test method such as: development of a model to assist engineering to determine if a non-destructive test (proof loading) could be utilized for bond integrity verification. This model would enable the supplier to reduce costs by minimizing the number of bond integrity destructive tests conducted while simultaneously continuing to position the supplier as a technical leader as an OEM automotive supplier.

Description of the Test Method

- A hood assembly that has been painted in primer is obtained.
- The specific pull-apart fixture hood nest is positioned under the 'A' frame of the test device and the hood to be tested is loaded into the nest.
- The latch pulling mechanism is positioned and connected onto the hood latch reinforcement.
- A vacuum is initiated to hold the hood down in the nest for the duration of the test.
- The air cylinder is activated to start pulling the hood latch reinforcement upward away from the outer shell until a complete failure occurs.
- The UTS is recorded along with the percentage of fiber tear.
- The test hood is removed and discarded

The destructive test method is referred to as a "pull-apart" test. The test apparatus is shown in Figure 1. A hood assembly that has been through the bonding and prime painting processes is used in this test. The pull-apart test apparatus literally pulls the inner panel from the outer panel. The apparatus has been designed to hold the outer panel securely in the fixture while simultaneously pulling on the hood latch reinforcement. The test has significant value to the supplier in regards to ensuring that the bonding process is producing hood assemblies that will not dis-bond or delaminate, during normal use.

The supplier developed the pull-apart test method since there were no procedures, tools, or instruments available to simulate the vehicle latch pull down loads. This test method and apparatus is a new technology, which is being turned into a viable engineering tool. The development of new technology is a reaction to problems and opportunities (Wright, 1992).

A technology leader actively searches for, evaluates, and develops technology alternatives (Stonebraker & Leong 1994). The supplier is considered a technology leader that develops new OEM processes.

Sheet Molding Compound (SMC) Bonding Process

Plastics can be joined together using different processes and techniques depending upon the material and performance criteria. In this case, the SMC joining process used to connect two panels together is called bonding. To bond the SMC panels together an adhesive is used between the SMC panels.

Bonding SMC components requires a fixture. The purpose of the fixture is to support or hold the components in the desired position or shape during the bonding process. The adhesive used to bond SMC components requires an external energy source to cure the material. The cure can be brought about by either thermal conduction, hot air from a forced convection oven, electromagnetic induction, microwave, and other similar methods (Kia, 1993).

The machine used to position the SMC components together and cure the adhesive is called a bond fixture. The bond fixture shown in Figure 2 consists mainly of a hydraulic press, bond tooling, machine controls, and part locating devices.

The hydraulic press moves on the vertical axis and contains the bond tooling, heaters, and control devices. The hydraulic press holds the bond tooling and opens for loading of SMC components, and closes to hold the parts during the bonding cycle.

The adhesive will not be fully cured in the short time period allotted to complete one bond cycle. It is crucial to ensure that the adhesive has obtained sufficient cure time to provide adequate strength to maintain part integrity during the remaining processes (Kia, 1993). The adhesive will undergo a final phase cure in the prime paint bake oven. The loads that that hood assemblies are required to meet are generated after they are primed and sent through the bake oven. The rate of cure is related to the temperature. As the temperature is increased during the bonding process, the adhesive rate of reaction (cure) will increase. At room temperature the adhesive used to bond the hood assembly will cure very slowly. The adhesive will obtain a significant cure during the heating and cooling phases of the bonding cycle (Kia, 1993).

Bond Adhesion Testing

The only test method recognized by automotive manufacturers is to certify bond integrity for a hood assembly by using a destructive test method. This test requires the hood outer panel be removed from the hood inner panel. The hood outer and inner panels are destroyed during this test. Once the panels are separated, they can no longer be bonded together to the

Figure 1. Pull-Apart Test Apparatus

Figure 2. Bond Hydraulic Press with a Bond Tool

existing panels or to panels that have yet to be bonded together.

The SMC used to form the hood outer and inner panels consists of cross-linking molecules through a process called polymerization. The adhesive must have cohesion greater than the adhesion of the materials used for making SMC panels. During the bond curing cycle, the epoxy molecules become entangled with the SMC molecules to form a secure bond (Michaeli, Greif, Kaufmann, Vosseburger, 1995). Figure 4, shows an exaggeration of the epoxy adhesive bond cross-section into the SMC panels bond seam (surface).

Figure 5, illustrates the basic sequence of the test.

Test Procedure

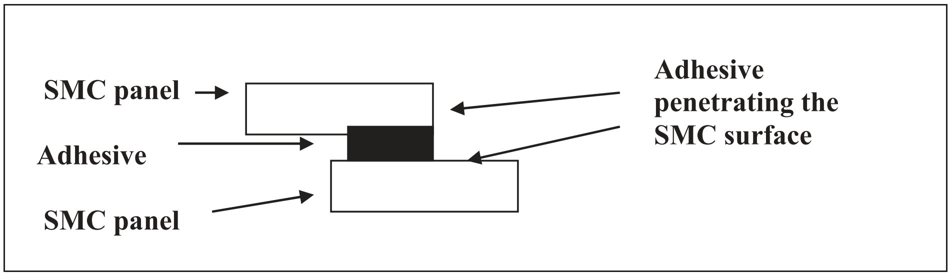
Initially, the test apparatus, and pull-apart fixture, were calibrated. This was a verification process to ensure the data obtained was accurate.

Each hood assembly outer panel was cleaned at the outer panel and vacuum cup contact surfaces with rubbing alcohol. The objective was to remove any foreign material that would prohibit the vacuum cups from maintaining a seal to hold the hood assembly outer panel in the nest during the test cycle. The hood assembly test procedure used was as follows:

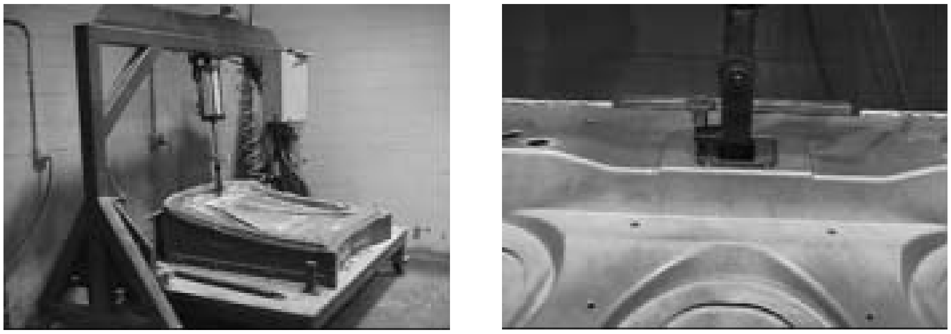
1) Visually inspect the hood assembly sample to ensure compliance to the specific scrap guidelines.
2) Clean the hood assembly outer panel vacuum cup contact surfaces with rubbing alcohol.
3) Load the hood assembly sample onto the pull-apart test fixture nest while ensuring the hood assembly is located within the guide rails.
4) Connect the clamp onto the hood assembly sample latch reinforcement and tighten the bolt with finger pressure.
5) Ensure all personnel are clear from the pull-apart fixture, activate the machine and videotape the control panel display (UTS, real time stress and real time strain).
6) At the completion of the test cycle, lower the clamp and remove the tested hood assembly sample from the pull-apart fixture nest.
7) Manually remove the remaining sections of the hood assembly outer panel from the inner panel.
8) Determine the percent fiber tear. Adhesive supplier technical support was utilized to calculate percent fiber tear for each hood assembly sample. *This will later be described as the tear down analysis.*

Another method of determining bond integrity is through a teardown analysis. These tears were generated in the pull-apart test. The tear down analysis is really an evaluation of the destruction caused in the pull-apart test. The result of the tear down test is a measure of fibers torn from the hood outer and inner panels. In Figure 6 a

Figure 4. SMC Panel and Epoxy Adhesive Bond Cross-Section

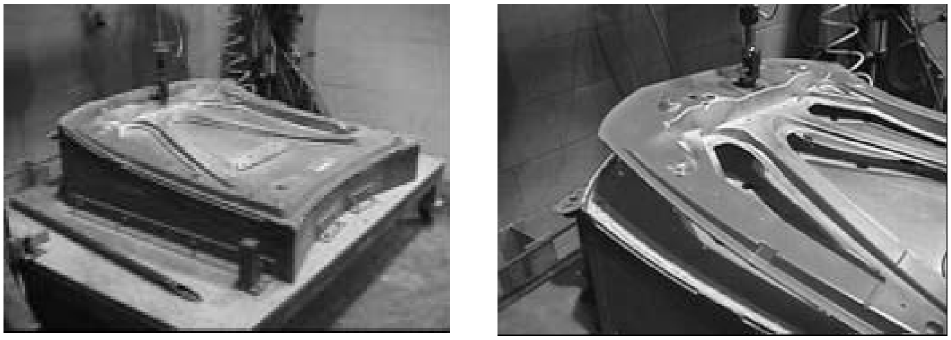


<u>Figure 5.</u> Pull-Apart Test



(A)
Hood assembly is loaded into the pull-apart fixture

(B)
Pull mechanism is fastened to the hood assembly



(C)
Pull-apart test is initiated

(D)
Pull-apart test is complete

section of torn fiberglass fibers from a hood assembly bond seam is shown.

A measure of the exposed fibers is taken to determine if the bond integrity meets the automotive specifications. The individual fibers are not counted, but the linear inches of exposed fibers are measured. A ratio of percent fiber tear is derived from the following equation in Figure 7.

To obtain the data to calculate the percent fiber tear requires special operator training to accurately interpret and measure the linear inches of fiber tear observed. Not all areas of fiber tear observed may be included into the fiber tear linear inches. Automotive applications require that there is a minimum width allowance of fiber tear required before it can be included into the calculation. Automotive companies also require a minimum width of adhesive, which is measured after bonding the SMC panels together.

Correlating Pre-yield Strength with UTS

The objective of controlling pre-yield strength with UTS is to determine if the strain value can be predicted at specific UTS observations. If there is a relationship, the UTS and corresponding strain values can assist in defining the plastic region of the stress-strain curve.

The hood assembly strain, stress and UTS data were obtained from the pull-apart test fixture's digital display. Each hood assembly sample pull-apart digital display was videotaped during the testing process. This videotape provided the necessary stress-strain data to plot thirty hood assembly stress-strain curves.

The plot in Figure 8, illustrates a pattern within the data points. The line indicates the best fit at each stress-strain interval. Initially as the stress increases, the impact of strain upon the hood assembly is held within a smaller range than the subsequent stress-strain points.

From the thirty hood assemblies processed through the pull-apart fixture, a plot in Figure 8 was developed. The objective of this plot was to visually identify if a common stress-strain performance could be identified along with the pre-yield strength and UTS. The maximum strain observed at the UTS point from 30 hood assemblies tested was 2.40 inches. Due to the fact that the hood assembly is now destructively tested, data points beyond the strain of 2.50 inches were not further evaluated for this study.

Figure 6. Exposed Fiberglass Fibers from a Tear Down Analysis

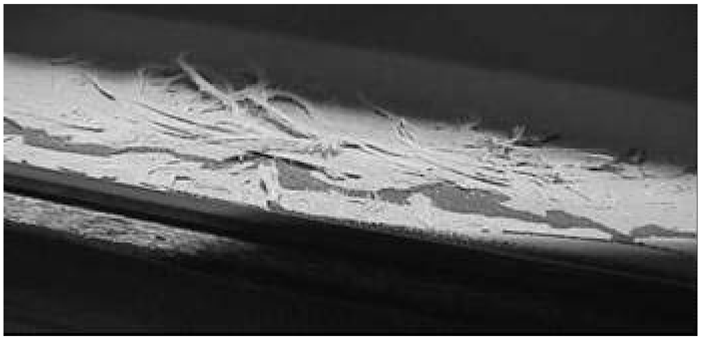
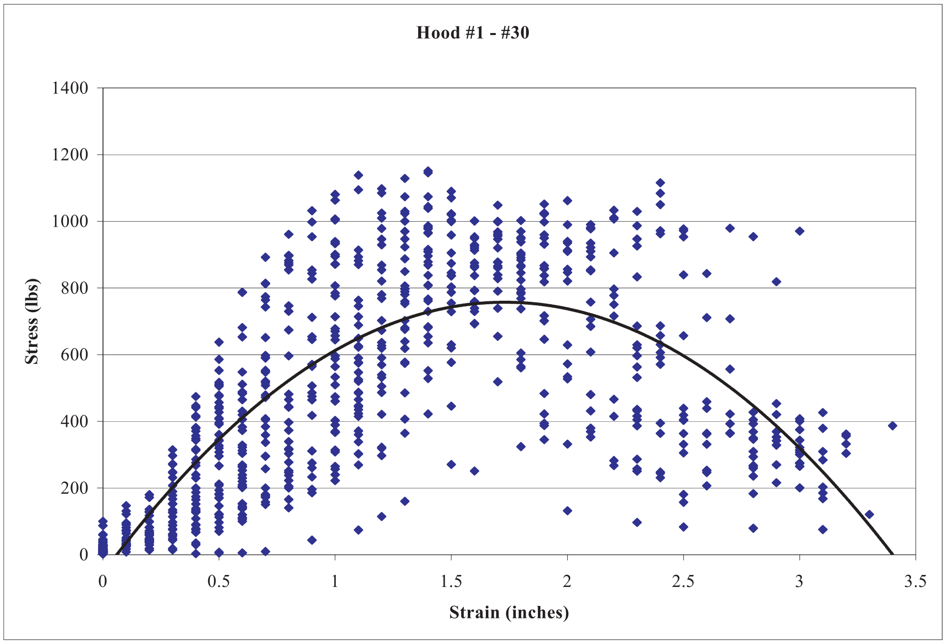


Figure 7. Percent Fiber Tear Equation

$$\frac{\text{Fiber Tear Linear Inches}}{\text{Part Bond Seam Linear Inches}} \text{ x } (100) = \text{Percent Fiber Tear}$$

Figure 8. Stress-Strain Plot for 30 Hood Assemblies with an Attempt at a Best Fit Curve



A linear regression model was constructed to identify if a relationship exists between UTS and strain at that point. In Figure 9, is the hypothesis for this regression model.

All the conditions have been met for normality and variance to verify this model. The r-value (0.022) is less than the significance level (a=0.05), which indicates a relationship, does exist between UTS and strain. The null hypothesis was not rejected. The linear regression analysis is shown in Figure 10.

The linear regression model supports the fact that the strain level cannot be predicted at specific stress loads. The model constructed based upon the individual observations indicated with a low R-Sq value that the model could explain 17.4% of the variation in stress due to strain as seen in Figure 10. The remaining 82.6% is unexplained, which made this a poor model for predicting strain.

Figure 9. Linear Regression Hypothesis

H_0: $_1$ 0

No linear relationship exists between UTS and strain

H_1: $_1 = 0$

Relationship exists between UTS and strain

5% significance level (=0.05)

Figure 10. Linear Regression Analysis for UTS and Strain

```
                    Regression Analysis

                 The regression equation is
      Strain (inches) = - 0.813 + 0.00220 Stress (lb.)

    Predictor      Coef       StDev        T       P
    Constant     -0.8130      0.9048     -0.90   0.377

    Stress     0.0021965   0.0009031      2.43   0.022

    S = 0.4152     R-Sq = 17.4%     R-Sq(adj) = 14.5%
```

Conclusion

The stress-strain curves do not have a definitive pattern to distinguish between the elastic and plastic regions. After UTS was obtained the stress load diminished and then increased, but remained below the UTS value. In fact, the strain levels overlapped at different stress load, which makes it difficult to identify the elastic or plastic regions.

The linear regression model indicated that a relationship does exist between strain and UTS, relative to the r-value of the test. The model also indicated that it would not explain the majority of the variation in stress due to strain. This model could not be used to predict different values of strain at various stress levels. This study suggests that a non-destructive proof load could not be determined.

It is recommended that additional testing should be conducted at stress load levels below 600 pounds to determine strain levels in the elastic region. Stress load levels from 400 to 500 pounds may be a good starting point for future studies.

A reproducibility and repeatability (R&R) study, as done in gage R&R, should be conducted on the pull-apart fixture. A review of the pull-apart fixture calibration process should also be performed.

The current process is capable of producing hood assembles that exceed customer load requirements. The test method required to determine hood assembly bond integrity is a destructive test method. As this study indicates, the elastic region could not be defined at the minimum load specification. Due to the overlap of the strain levels, a non-destructive proof load test method cannot be implemented.

References

1. Kia, H. G. (1993). Sheet Molding Compounds: Science and Technology. Cincinnati, Ohio: Hanger/Gardner Publications, Inc.
2. Michaeli, W., Kaufman, H., Grief, H., Vosseburger, F. J. (1995). Training in Plastics Technology. Cincinnati, Ohio: Hanger/Gardner Publications, Inc.
3. Stonebraker, P. W., Leong, G. K. (1994). Operations Strategy. Needham Heights, Massachusetts: Allyn and Bacon.
4. Wright, R. T. (1992). Technology Systems. South Holland, Illinois: The Goodheart-Willcox Company, Inc.