Case Study:
University of California, Irvine

MSC Nastran Helps Perfect New Nondestructive Testing Method for Adhesive Bonded Composites

Overview

Compared to other joining methods, bonding composite structures with adhesives distributes the load over a larger bond area, reduces weight, joins dissimilar materials and provides higher stiffness and toughness. Bonding also generally reduces manufacturing costs. However, when using adhesive bonding for composites it can be very difficult to determine if the bonded joint meets structural requirements without destroying the part. Substandard bonds called kiss bonds occur when adhesive shear strength is low due to contamination on the bonding surfaces or improper handling, mixing or curing of the adhesive. Many kiss bonds result from poor surface preparation of as-molded surfaces due to excess fluorocarbons, silicones or plasticizers introduced during the manufacturing process. If these contaminants are

Quantitative percussive testing

"With the high cost and lead-time involved in building test panels, (MSC Nastran) will substantially reduce the time and cost required to bring this new technique into widespread use."

Scott Povermo, Researcher, University of California, Irvine

not removed, they may decrease the surface energy, which in turn reduces the contact angle between the adhesive and the bonding surface, resulting in a reduction in shear strength. In many applications, concern with kiss bonds makes it necessary to use metal fasteners in addition to the adhesive bond to ensure joint integrity. The addition of fasteners increases weight and manufacturing costs.

Challenge

Conventional nondestructive testing methods are not able to detect kiss bonds within a composite structure. Researchers at the University of California, Irvine including Graduate Student Scott Poveromo and Professor James Earthman, are working on applying quantitative percussion testing to determine bond integrity in laminate composite samples. Quantitative percussion diagnostic (QPD) testing was originally developed to measure the damping capacity of human teeth and dental implants. A stainless steel rod containing a force sensor is accelerated by an electromagnetic coil to a predetermined velocity. The electromagnetic coil is deactivated just prior to impact with the specimen so only the kinetic energy of the rod is administered to the specimen. The impact of the percussive rod generates a nondestructive stress wave that propagates through the specimen. A computer interfaced to the sensor on the percussion rod determines the mechanical energy returned to the rod, the energy dissipated by the sample and the loss coefficient, which is proportionate to the energy dissipated by the sample divided by the total strain energy.

"Our experiments demonstrated that kiss bonded panels recorded significantly lower maximum force values and higher loss coefficients when averaged over several different locations in the sample," said Scott Poveromo, Ph.D. Candidate in Materials Science at UCI. "Now we are working on fine-tuning the quantitative percussion testing method in order to enable its use in real world inspection applications. We need to get a much better understanding of the capabilities of this technique in inspecting adhesive bonds. For example, we need to determine the size of the smallest kiss bonded area that can be detected. Achieving this goal through physical testing alone will require building many laminates that cost thousands of dollars. This physical testing approach also presents the danger that errors in the manufacturing process could skew the results."

Solution/Validation

UCI researchers used MSC Nastran and Patran to simulate the operation of quantitative percussion testing to reduce the need for physical testing and eliminate the potential for manufacturing errors. They used the MSC Nastran implicit nonlinear solver (SOL 400) to analyze a 0.32 ms impact event in 10 µs time increments. UCI researchers modeled a 102 mm by 102 mm (4 by 4 inch) secondary bonded carbon fiber-epoxy composite laminate with 3-dimensional hexagonal orthotropic elements with 6 faces and 8 nodes per element. The 0.23 mm (0.009 inch) thick epoxy adhesive bond was modeled with four 0.06 mm (0.0023 inch) thick elements. The panel was constrained with 3-point displacement using nodes on back edge of panel. A symmetry plane was used to reduce the size of the model by 50% to about 380,000 elements. The AS4 carbon plain wave fabric/epoxy matrix has a modulus of 6.9 GPa (106 psi). The FM-300-2 epoxy film

Key Highlights:

Product: MSC Nastran

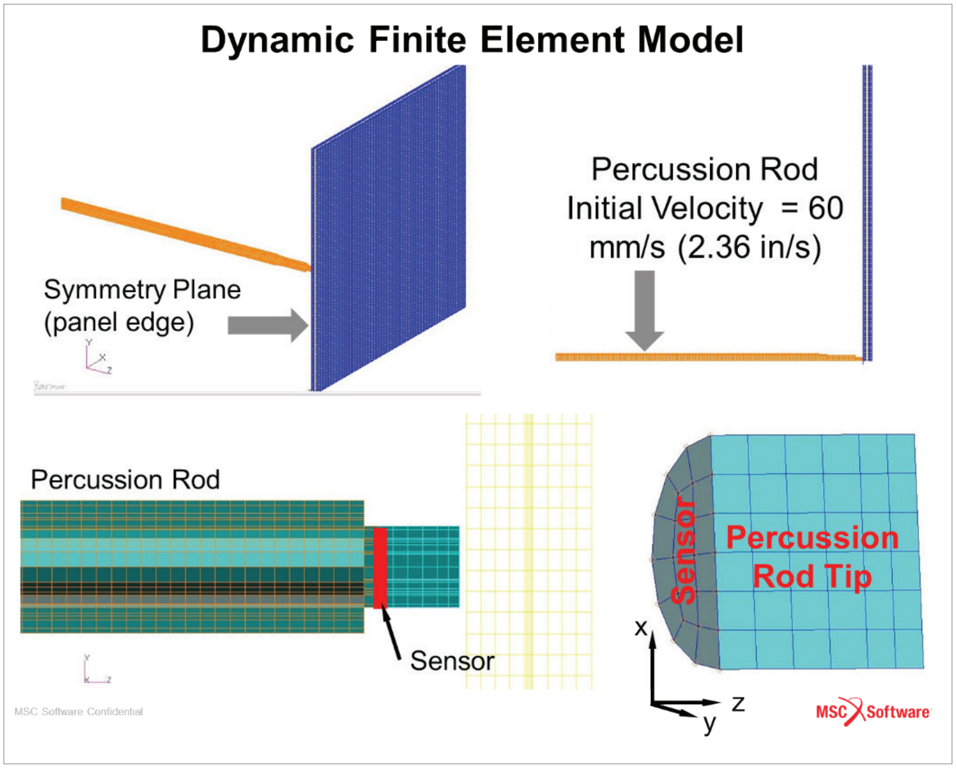
Industry: Manufacturing

Benefits:

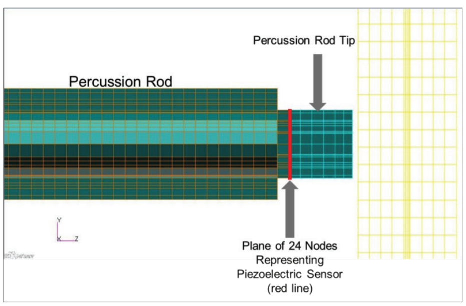
- Reduce the need for physical testing
- Eliminate the potential for manufacturing errors
- Perfect the use of percussive testing in a wide range of applications.
- Evaluate the ability of the test to clearly distinguish between well bonded and kiss bonded panels.

Figure 1. Periometer® instrumentation manufactured by Perimetrics, LLC.

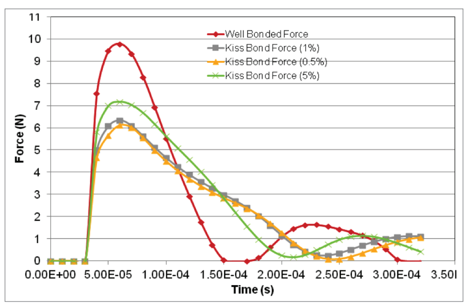
Figure 2. Performing QPD measurements on bonded carbon fiber reinforced composite laminates.



Finite element model



Prediction of percussive force



Simulation prediction of contact force (z dimension) for well bonded vs kiss bonded panel

Panel Description	Max Force (N) at 60μs	% Change from Well Bonded Panel
Well Bonded Panel	9.77	NA
Kiss Bond Panel (5%)	7.17	26.58
Kiss Bond Panel	6.34	35.15
Kiss Bond Panel (0.1%)	6.11	37.48

Table 1. Summary of Predicted Maximum Force Values for Values for Well Bonded and Kiss Bonded Models.

adhesive has a modulus of 2.4 GPa (3.5 x 105 psi). The kiss bond was simulated by reducing the adhesive modulus to 0.5%, 1%, and 5% of the normal value. The stainless steel percussion rod has a modulus of 207 GPa (3 x 107 psi). The percussion rod was given an initial velocity of 60 millimeters per second (2.4 inches per second). The force was predicted in the simulation at the piezoelectric sensor, the same point at which it was measured in physical experiments. The FEA simulations predicted percussion force values that closely matched physical experiments (Max Force ~ 7N) as shown in Table 1.

Results

"We have validated the ability of MSC Nastran to predict the percussion force generated when performing quantitative percussion testing on well bonded and kiss bonded laminate panels," Poveromo said. "Now, we are beginning to use simulation to perfect the use of percussion testing in a wide range of applications. For example, we can change variables such as the impact velocity and the area in which the kiss bond occurs and evaluate the ability of the test to clearly distinguish between well bonded and kiss bonded panels. With the high cost and lead-time involved in building test panels, FEA will substantially reduce the time and cost required to bring this new technique into widespread use."

About University of California, Irvine

UCI has more than 29,000 undergraduate and graduate students, 1,100 faculty and 9,400 staff. The Department of Chemical Engineering and Materials Science has expertise in areas spanning biotechnology and molecular engineering, chemical separations and extraction, molecular modeling and computation, transport phenomena, interfacial science, nanostructures and nanoelectronics, and advanced materials characterization.

For more information on MSC Nastran and for additional Case Studies, please visit **http://www.mscsoftware.com/product/msc-nastran**

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