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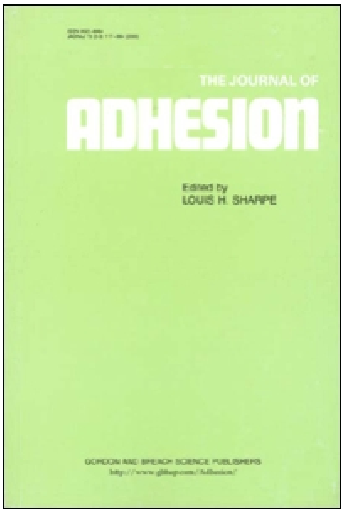

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Overview: Fracture Control of Adhesively Bonded Components

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Overview: Fracture Control of Adhesively Bonded Components†

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In recent years increased use of adhesive joining has occurred because improved adhesives have become available and adhesive joining is ideally suited for many highly stressed lightweight structures. Notable among the ideally suited applications are panels and components employing honeycomb-skin construction and high performance fibrous composites.

With regard to joining highly stressed primary structure, techniques such as bolting, riveting and welding often have been preferred in the past because adhesive bonds have had a reputation for low unit strength and lack of reliability. This reputation is not without foundation in fact. However, the introduction of a process such as adhesive joining to a technology where it previously has not been used, inevitably involves a "learning curve". This "learning curve" applies to the designer and stress analyst, the materials, process and fabrication engineers, as well as the production personnel. Basically these people must learn the advantages and disadvantages, and the do's and don'ts of joining with adhesive bonds.

When the nearly horizontal portion of the "learning curve" has been reached, it still may be said that the adhesively bonded structures exhibit room for improvement. Three areas that deserve attention are the low strength portion of the unit strength scatter band, the life-time that can be predicted and achieved under conditions of service (severe cyclic loading, temperature extremes and thermal stresses, and gaseous and liquid environments), and the static strength that can be anticipated at various times during this life.

It is clear that communications and cooperation among the several groups involved in a final product (including the designer and stress analyst, the materials engineer and polymer and surface chemist, the production

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† First presented as fracture mechanics.

personnel, and the test engineer) is essential to produce an adequate product.

The designer asks for stress values that are suitable, for example, for a lap joint subjected to a given load spectrum in a particular environment (say salt spray with a temperature range from 40°F to 250°F) for a period of 4000 hrs. of service spread over a 10-year period. The materials engineer and chemists select several of the new, outstanding adhesives from a large group based on a simple, quick, laboratory test (such as a peel test) and ask the test engineer to perform accelerated life tests on lap joints to simulate the environment and load spectrum for the desired life. The test engineer turns to the designer and stress analyst and asks if his test specimen will properly simulate the local stresses of the intended structure. Next he turns to the materials engineer and chemist and asks if the proposed test will properly accelerate the influence of the environment on the life.

When each of these difficult questions is settled, the production group is instructed to make the specimens for the test that will provide the designer with his starting point, the nominal stress level that will allow him to "design" the structural joint. The production group will ask for guidance from the materials engineer on how to shorten and simplify the fabrication process in order to meet the production schedule and reduce costs.

When the first group of specimens are completed and subjected to simulated service test conditions, some small percentage of the specimens probably will fail prematurely. These premature failures will be traced to flaws inadvertently built into the adhesive joint. As experience has taught many of us, each adhesive joint must be inspected non-destructively prior to test or service to insure that the accidental flaws will not impair the structural integrity of the final product.

Management may inquire why the production group produced a "flawed" adhesive joint. An investigation may assign responsibility to any one or combination of causes from careless workmanship, lack of adequate quality control in accepting materials, storage of materials for too long a time, inadequate surface cleaning, and handling, including plant contamination, or lack of adequate production control (temperature, heating and cooling rates, pressure), etc.

A very common cause for premature failures is lack of adequate communication and cooperation between people; this problem is not unique to the production of suitable adhesive joint specimens but occurs in all phases from research on adhesive joints to mass production of adhesively bonded structures. Like many other areas, this is an inter-disciplinary area that makes very slow progress when any of the important groups work in isolation from the others.

In the four papers that follow, we report on an inter-disciplinary effort (disciplines of metallurgy, surface chemistry and mechanics are represented) in research on adhesive bonds. The purpose of the work was to characterize the crack extension behavior of flaws (cracks) in adhesive bonds under load and in the presence of various environments (temperature and gaseous or liquid media). The results of these experiments are useful and needed to evaluate the significance of flaws on structural integrity of adhesively bonded specimens and structures.

The approach assumes that flaws will be one of the most common causes of premature fracture of adhesively bonded specimens or components in either a simulated service test or actual service. The most severe flaw configuration is a large, sharp crack. Small cracks will grow under service loading (steady or cyclic) and environment, first slowly when the crack is small and more rapidly as the crack becomes larger. When the crack reaches a critical size for the applied loading, the crack extends rapidly causing fracture failure of the adhesive joint.

A measurement of the combination of nominal stress, σ, and crack size, $2a$, at the onset of rapid crack extension leads to a measure of fracture toughness, designated either K_{Ic} or $\mathcal{G}_{Ic}$ of the adhesive bond. Additional measurements of the rate of crack extension, either da/dt under steady load, or da/dN under cyclic loading, or da/dN under a combination of cyclic loading and environment (at frequency, ν), allows estimation of the crack size at any stage during the life that will cause fracture of the adhesive bond at the end of life. Specifically the crack size at the beginning of life (that just causes fracture at the end of life) becomes important as the largest size initial flaw that will not cause premature fracture. Non-destructive inspection methods must be capable of detecting this initial flaw (hopefully smaller cracks also) if the inspection (at beginning of life) is to insure an adequate life and structural integrity of the component.

This approach to structural integrity is adopted from experience with metal structures. Application of linear elastic fracture mechanics parameters to describe fracture toughness and crack extension rate leads to the concept of a "fracture control plan". The fracture control plan organizes measurements of fracture toughness and crack extension rate, to provide an estimate of the maximum initial flaw size and the necessary inspection methods at the beginning of life and possibly during service that will insure that the component does not experience premature fracture.

The "fracture control plan" does not surplant the conventional materials selection, design and development process described earlier. Instead it provides a "parallel path" to structural integrity. It deals with and quantifies features that were only qualitatively specified in the conventional development process. Among these features are the toughness of the adhesive bond and the size of cracks that impair structural integrity. These cracks must be found by NDI techniques and removed.

In the four papers that follow, a number of the variables that influence fracture toughness and crack extension rate of adhesive joints are explored. It is clear that while the present work is rather extensive, the work that remains to be accomplished in this area is considerable. Specifically it is noted that tests that are appropriate for materials (adhesive) selection such as the peel test are not directly interpretable in terms of fracture toughness measurements or crack extension rate measurements. Similarly structural type design data tests are difficult to interpret in terms of unambiguous fracture toughness measurements or crack extension rate measurements.

Thus for the present time, it appears advisable to view the fracture toughness and crack extension rate measurements as additional measurements that neither replace nor are replaced by conventional tests. In applications where structural integrity is paramount, the price of the additional features of the fracture control plan will be small compared to the loss due to fracture of one or several structures or vehicles. In other applications, the savings in maintenance and repairs will pay for fracture control.

In summary, the success of future applications of adhesive bonding to highly stressed primary structures depend upon communication and cooperation among the several disciplines involved. The four papers that follow result from such a cooperative effort applied to research into the factors that influence fracture toughness and sub-critical crack extension rates.

Reliability of adhesive bonds can be greatly increased by the application of a fracture control plan. Such a plan combines knowledge of local stresses in an adhesive bond with fracture toughness and crack extension rates (under service conditions) to estimate the maximum allowable crack size at the beginning of life that will not cause fracture during the specified life. Non-destructive testing and evaluation must be employed to insure that all flaws and cracks are smaller than this allowable initial size. With the understanding that the member is not overloaded or otherwise abused, reliability is assured.