Pergamon

Int. J. Solids Structures Vol. 32, No. 17/18, pp. 2829–2831, 1995
Elsevier Science Ltd
Printed in Great Britain
0020–7683/95 $9.50 + .00

0020–7683(94)00290–8

DYNAMIC FAILURE MECHANICS OF MODERN MATERIALS—A SUMMARY OF THE FIRST DISCUSSION SESSION

(Prepared by J. W. DALLY)

Professor Dally opened the discussion by stating that he had requests from Dr Robert Schmidt and Professor K. Ravi-Chandar to present new material related to papers presented earlier in the Workshop.

The discussion by Dr Schmidt related to the problem of a possible failure of the space station that is currently being designed under the direction of NASA. This problem was introduced by Dr Mel Kanninen and described in additional detail by Professor Sia Nemat-Nasser. This problem involves the impact by orbit debris of a large diameter, very thin-walled pressurized cylindrical tube. The tube is expected to be perforated, but the question is will the tube vent from the perforation or will it unzip due to rapid unstable crack growth. Since the safety of those individuals in the space station depends on the cylinder venting, the question is of considerable importance.

Robert Schmidt described the approach that Boeing was employing in addressing this problem. They have impacted pressurized test cylinders with simulated orbit debris at velocities of 7 to 12 km against the bumper shield. The cylinders were fabricated from 2219 T87 aluminum alloy (this material is similar to the more common 222 aluminum alloy in that it can be welded but it is tougher). They also employed a miniature shaped charge to produce cracks in the pressurized vessels. They were able to induce precision cracks growing at a rate of 0.25 in/μs in the form of either a four leg pedal or a two leg straight crack. They also conducted tests on small scale cylinders with wall thicknesses of 0.038 in and diameters ranging from 3 to 12 in. The results of several tests were displayed on a graph with p/p_b on the ordinate and $a\sigma_u/(rt)^{1/4} K_c$ on the abscissa. The symbols used are:

p and p_b are pressure and burst pressure
a is the half crack length
σ_u is the ultimate strength
r and t are the radius and thickness of the shell
K_c is the fracture toughness.

The data points define a straight line on this dimensionless graph with the vent behavior in the area left of the line and the burst unzip behavior in the area right of the line. The design of the space station is based on $p/p_b = 0.1$, which implies that cracks of 7 to 8 in long will be stable depending on the thickness of the shell.

Dr Schmidt went on to describe other experiments with pressurized cylinders which were exposed to local hot spots produced either with a laser spot or a jet of burning oxygen acetylene mixture. Although the alloys were different in these experiments, the results compared favorably with those described previously when the dimensionless parameters characterizing either vent or burst behavior were used for the comparison.

In the discussion following this presentation, Professor Dally noted that crack propagation in a pressurized cylinder is a very old problem that dates back to the 1950s. Three of the new Comet jet airplanes which were pressurized failed before it was recognized that the short fatigue cracks which had developed at the corners of the rectangular windows represented a long double ended crack across the diagonal of the window.

Professor Albert Kobayashi was concerned that the tests conducted by Boeing did not take into account the effect of the stiffeners. He went on to state that the tear strap (double the skin thickness) that is riveted to cylinders used in airplane construction is effective in arresting cracks. The tear strip is bent in the arrest process and absorbs sufficient energy to stop the crack growth. Even though the stiffeners on the space station are integral, they must be considered because they will tend to keep the crack closed.

Dr Schmidt responded by stating that the stiffeners on the space station are designed to reinforce the shell to resist the launch loads and not as arresters to prevent the cylinder from unzipping. Also, the stiffeners are on 16 in centers which is too far apart for them to be effective in arresting cracks.

Dr Schmidt concluded his response to Professor Kobayashi by asking the audience to comment on the validity of small scale tests to study fracture problems of this type.

Professor Ares Rosakis responded that he was doubtful of the validity of small scale tests in predicting fracture behavior. Even in static problems the fracture mechanisms depended on the size of the fracture process zone and the plastic zone. In the dynamic problem there were additional complications such as stress waves and the reflection of these waves from nearby boundaries. Professor Rosakis indicated that care was necessary in interpreting the results of sub scale tests and interpreting even the experimental technique employed in the measurements.

Dr Schmidt responded by stating that the small scale tests could be used to verify the dynamic codes which could then be used in the analysis of the larger structures.

Professor K. Ravi-Chandar then described some ongoing experiments with two dimensional sheets of polycarbonate. The fracture specimens were fabricated as a single edge notch type with relatively short cracks. The specimens were loaded by impact of a flat fronted projectile on the edge of the specimen just above the crack line. The results observed depended markedly on the impact velocity. At very low velocities, the specimen yielded in the local region of the crack tip and two very short extensions of the crack occurred at an angle of $\pm 45^{\circ}$. For moderate velocities a single crack was initiated that propagated a significant distance. The failure was clearly brittle. The orientation of the crack path indicated that the mechanism of failure was maximum principle stress. For very high speed impact, an adiabatic shear band was produced at the crack tip and extended for a short distance. Clearly this failure was again ductile and the mechanism was strain dominated shear yielding.

The fracture surfaces were examined under high magnification. The surfaces associated with brittle failure exhibited many closely spaced parallel striations indicating a high frequency small angle variation in the path of the crack. The fracture surface produced by adiabatic shear band growth was totally different. The fracture surface exhibited regions where localization, melting and tearing occurred.

Professor Ravi-Chandar indicated that studies of the constitutive modeling of the fracture process are important. It is essential to determine the mechanism of the initiation and the growth and to determine if these mechanisms are controlled by stress or by strain.

In a discussion of this presentation, Professor Alan Needleman indicated that micromechanical modeling was in one sense advantageous in these studies. You can define a mechanism and build a simulation process with predictive capability. On the other hand, the disadvantage of this approach is that the general features of the fracture process are hard to detect. Also, models with two competing mechanisms are often needed.

Professor Ravi-Chandar responded by stating that in his experiments there were two competing mechanisms and the microscopic stress field suppressed one mechanism and supported the other.

Dr Bertram Broberg concurred with this observation and described his own experiments with mode II crack growth in plates of PMMA. In his experiments he cut an inclined crack in a uniaxial member and loaded it in uniaxial tension until the cracks became unstable. He observed that these cracks grew in mode I although clearly the K_{II} was larger than K_I. He then added hydrostatic compression to the applied stresses and noted that the cracks initiated and grew due to K_{II}. The mode I behavior was suppressed by the presence of the compressive hydrostatic stresses. His measurements indicated that $K_{IIc}/K_{Ic} = 2.5$.

Professor Arun Shukla then described experiments that he and Professor Ravinder Chona had conducted with cracks propagating along a curved path and indicated that K_{II} was essentially zero. The curvature was due to the higher order terms in the mode II series expansion describing the stress field. This comment involved response from several researchers.

Professor Wolfgang Knauss indicated that he and Professor Ravi-Chandar had observed crack curvature when the propagating crack interacted with a stress wave. Under transient conditions mode II exists for a very short period (10 μs) and the crack responds by turning.

Dr Broberg indicated that fractures in earthquakes are often due to mode II loading. The mode I effects are constrained by gravitational (compressive) stresses.

Professor Kobayashi indicated that the mode II propagation was unusual but it could occur.

Dr Jonathan Epstein introduced the topic of the interface crack and commented that the crack growth at the interface was rare. The cracks may initiate at the interface but they curve and move away from the interface.

Dr Broberg concurred and noted that in welds, the cracks propagate parallel to the weld base plate interface but they propagate in the base plate.

Professor Ravi-Chandar then raised a question directed to Professor Rosakis about his PMMA/Aluminum interfacial experiments with variable strength interfaces. These interfaces were between aluminum and PMMA plates. Professor Ravi-Chandar asked if the Rayleigh wave speed of PMMA could be exceeded in PMMA/Aluminum interfaces with a zero strength joint. Professor Rosakis replied that he observed crack interfacial crack tip velocities that exceed the Rayleigh wave speed when the adhesive joint was strong. In this case, energy would be delivered from the aluminum plate into the PMMA to support the crack velocities higher than the Rayleigh wave velocity of PMMA. However, when the adhesive strength of the joint was weak, the maximum velocity was the Rayleigh wave velocity of the PMMA.

Professor Kobayashi returned the point raised by Dr Epstein, that the cracks will not propagate at interfaces even if the adhesive joint is weak. He related his experience with fracture experiments on the space shuttle. The shuttle tiles are mounted to the shuttle body with a soft and weak adhesive system consisting of RTV and felt. When a crack is introduced in the interface and the system is subjected to mode I loading, the crack propagates out of the interface and extends in the tile.

Dr Broberg called attention to papers by Professors Tony Evans and John Hutchinson, which predict these observations.

Dr Epstein indicated that numerical analysis by Professor David Parks suggested that the deviation from the interface was accompanied by a significant elevation of the hydrostatic stresses which in turn would elevate the yield and perhaps change the mechanism of failure in the materials adjacent to welds.

The discussion was closed on this note as the time available had been extended.