brittle lacquers to predict the direction and approximate magnitude of surface stresses on machine and structural parts. In other applications, however, such as transparent enclosures on aircraft, transparent instrument panels, and as insulators in electronic apparatus, the initiation of crazing is cause for alarm either because of loss of transparency, loss of mechanical strength, or loss of dielectric properties as a result of moisture absorption in the crazing openings. Also, since crazing once started will continue to increase without increase of load magnitude, it is well to avoid its consequences by taking every precaution to avoid its inception.

As already noted, surface coatings are helpful and can be recommended. Also, working-stress magnitudes should be established not merely on the basis of static ultimate strength, but on strength values at which crazing is found to occur. In applications where the plastic part may be subjected to tensile stress in varying directions, full annealing of the transparent plastic sheets is highly desirable as in this way the material can be made more nearly isotropic. On the other hand, if the plastic part is to be used only under uniaxial tension, then higher working stresses can be obtained, without danger of crazing, by use of highly oriented material. Essentially, the reason is that in the oriented state all the molecular chains tend to align in the direction of orientation and crazing, which is thought to be a result of lateral separation of adjacent chains (4), cannot then occur. Of course, crazing will occur in oriented materials and at low stress values if transverse tensile rather than axial tensile stress is applied. If, therefore, the intended application is such that there is a probability of lateral as well as longitudinal tensile stresses occurring, then the isotropic annealed state is preferable to the highly oriented state.

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Discussion

A. G. H. Dietz.[4] The authors have made interesting and valuable observations respecting crazing, a phenomenon of considerable practical and theoretical importance in the use of many plastics.

Of considerable interest is the observation that crazing starts at the surface and proceeds inward. This has been discussed informally by many observers, and some have maintained that on highly polished specimens in which even minute surface flaws have been removed, crazing may begin in the interior simultaneously with surface crazing. The writer has not had occasion to study this phenomenon closely, but would welcome comment by the authors.

When specimens are oriented by drawing, orientation appears to begin at the surface and to proceed inward as the degree of orientation increases. One of the first effects of orientation is the diminution and gradual disappearance of crazing. In partially oriented specimens, surface crazing disappears but internal crazing still occurs; the surface fracture at failure becomes fibrous whereas internal fracture remains abrupt or "brittle." When orientation proceeds far enough, fracture throughout the specimen becomes fibrous and crazing disappears altogether.

Authors' Closure

The authors wish to express their appreciation to Professor Dietz for the interest he has taken in this paper and for the comments he has made.

With regard to the occurrence of crazing in the interior, simultaneously with surface crazing for highly polished specimens, the authors wish to make the following comments. As it has been stated, various factors such as temperature, time, orientation, and environment have an influence on the initiation of crazing, but local stress intensity is probably more directly responsible for its occurrence and subsequent propagation than any other factor. If a simple tension specimen is highly polished so that there is no surface contamination or any stress concentration under loading, and particularly if it has no preferred molecular orientation, it appears, then, that the local stress intensities will be uniform over the cross section as well as the gage length of the specimen and it seems that there is no reason why crazing may not begin in the interior simultaneously with surface crazing. Furthermore, it could be expected that internal crazing would occur first if tensile residual stresses are present in the interior of the specimen.

The understanding of the effect of orientation on strength and crazing properties of linear high polymers has been advanced through the development of a theory which permits calculation of strength as a function of orientation in terms of strain change (12) as well as prediction of crazing. It is expected that a report on this subject will be published by the authors of this paper in the near future. In general, the statistical theory analyzes the effect of orientation of linear polymeric molecules on strength and crazing by considering their microstrength and their direction of orientation. Evidences commented on by Professor Dietz seem to support the theory fairly well. Various experimental investigations in connection with both uniaxially and biaxially oriented specimens are being carried out by the authors' group and verifications as well as modifications of the theory will be made.

The authors wish to also express their appreciation to Prof. Bryce Maxwell for his interesting remarks on the initiation of crazing, which he made orally following the presentation of the paper. Referring to reference (7) of the paper concerning his

[4] Massachusetts Institute of Technology, Cambridge, Mass. Mem. ASME.

work he commented that under all conditions studied the criterion for the initiation of crazing is the strain in the material and by varying time or temperature this can be studied independently of stress. Then he attempted to show the agreement of the critical crazing strain obtained from both his work and that from Fig. 14 of the paper by extrapolation. A strain corresponding to a stress of approximately 1650 psi for zero rate of propagation of crazing would be 0.36 per cent which agrees quite nicely with the critical crazing strain of 0.35 per cent of reference (7).

However, the authors wish to point out the difference between the zero rate of propagation of crazing and the zero penetration of crazing, which may also be referred to as the critical crazing point. Referring to Fig. 13 of the paper and assuming that all crazing curves were straight lines and would intersect at the point as shown at the lower left corner of the figure, a stress of about 2100 psi corresponding to the zero penetration of crazing could be obtained from Fig. 14, whereas the stress for zero rate of penetration of crazing is only around 1650 psi.