DISCUSSION

W. F. Brown, Jr.,[1] *and M. H. Jones*[1] *(written discussion)*—Some of the data reported by Dr. Steigerwald were obtained apparently before ASTM Committee E-24 formulated the present Proposed Method of Test for Plane Strain Fracture Toughness of Metallic Materials, and represent tests using different types of instrumentation than specified in the ASTM Committee E-24 Method. We wonder if these differences might affect the measured toughness values. Thus, the apparent plane strain fracture toughness results for H-11 shown in Figs. 1 through 5 correspond to the load required for the "initiation" of crack growth as indicated by the appearance of a discontinuity (pop-in step) in a record of load versus change in electrical resistance of the specimen or a deviation of this record from linearity. The electrical resistance should be much less sensitive to plastic flow than the crack mouth displacement measurement specified in the ASTM Committee E-24 Method. Furthermore, this Method specifies a fixed percentage of apparent crack extension as a basis for selecting the load used to calculate K_Q. Strictly speaking, we would expect agreement between fracture toughness values obtained by the ASTM Committee E-24 Method and Dr. Steigerwald's electrical resistance technique only for very brittle behavior (for example, the subzero test records in Figs. 2 and 4 of the author's paper).

Dr. Steigerwald suggests that the present crack length and thickness requirements of the ASTM Committee E-24 Method could be reduced. A modification of the thickness requirement is based on the data for the H-11 steel. For the reasons mentioned above we would be very cautious regarding any implications of these data concerning specimen size requirements as they relate to the present ASTM Committee E-24 Method. The results obtained for D6ac and 2024T851 aluminum alloy, Figs. 8 and 9, are cited as evidence supporting a reduction in the crack length requirement. While the total variation in fracture toughness values was small for the aluminum alloy, these data appear to support the present crack length requirement. The D6ac steel data scatter rather badly with the extreme values being approximately ± 25 percent of an overall mean of about 60 ksi $\sqrt{\text{in.}}$ This can be compared with the spread of about ± 9 percent for valid K_{Ic} values of 4340 steel reported by

[1] Chief and research engineer, respectively, Strength of Materials Branch, NASA Lewis Research Center, Cleveland, Ohio 44135.

Heyer and McCabe[2] from results of the ASTM Committee E-24 round-robin program. In our opinion the trend line shown by the author in Fig. 8 could just as well have been drawn with a positive slope and the data used to support an argument for increasing the crack length requirement rather than reducing it.

While we would agree that the size requirements will vary with the material fracture characteristics, it is necessary to formulate them in such a way that applicability to a wide variety of materials is ensured. With this in mind we have always believed that both the crack length requirement and the thickness requirement should be *increased,* not reduced. This belief appears to be supported by the data for Hylite 50 reported by May.[3]

We would appreciate the author's comments on his reason for comparing the various steels in terms of K_{Ic} on the basis of tensile strength rather than yield strength. The order of rating would in many cases be different depending on which of these two bases were used. More specifically, it is not clear to us how the strength potential of a metallic alloy can very much exceed the yield strength in normal structural applications.

E. A. Steigerwald (*author's closure*)—The four points raised by Messrs. Brown and Jones are:

1. The validity of the K_{Ic} values obtained from resistance measurements on sheet specimens.
2. The validity of the ASTM criteria for crack length and specimen thickness.
3. The variation in apparent fracture toughness that occurs by relaxing the ASTM crack length criterion.
4. The reason for plotting K_{Ic} as a function of tensile strength rather than a function of yield strength.

I will try to answer each of these points in order. Heat tinting methods indicated that the resistance technique had the ability to detect crack extensions of the order of 0.005 in. On this basis most of the fracture toughness values in the transition range did conform to the ASTM Committee E-24 criterion, but those above did not. Therefore, the K values listed as "Plane Strain Fracture Toughness" on the right hand ordinate of Figs. 1 and 3 should be more accurately termed "Fracture Toughness" to avoid the indication that they represent valid plane strain values over the entire test temperature range. This correction, however, does not alter the basic purpose for presenting the sheet data which was to show a correlation between the nature of the crack growth initiation (pop-in) and the fracture mode transition in sheet materials.

[2] See p. 22.
[3] See p. 42.

I do not recommend that the ASTM criteria for either thickness or crack length be reduced. The recommended practice should be applicable to a wide range of materials and not relaxed. I am in complete agreement with Messrs. Brown and Jones on this point which is really the basic philosophy presented in the discussion. The purpose of indicating that in some materials the K value is not significantly altered by crack lengths in the range between $1.0(K/\sigma_{ys})^2$ and $2.5(K/\sigma_{ys})^2$ is to provide a proper perspective to engineers who often do not have the luxury of test data on very large specimens. In fact the data shown in Fig. 6, aluminum alloy DTD 5074, and Fig. 8, maraging steel, of May's paper[3] is in complete agreement with the conclusion obtained in my paper from the 2024 tests concerning crack size effects. May's data on Hylite 50 cited by Brown and Jones also is relatively insensitive to crack size effects. In general, however, as May points out, the results for Hylite 50 are anomalous and do not give constant K_{Ic} values when ASTM recommended practice is followed.

The various steels are compared on the basis of tensile strength in hopes of providing a more sensitive and perhaps more meaningful correlation with fracture toughness. High-strength steels such as 4340 can be tempered over a range of temperatures to provide a variety of structures. Tensile strength is very sensitive to tempering temperature while yield strength often is not (for example, 4340 steel tempered in the 400 to 600 F range). The tensile strength was then selected because it was believed to provide a parameter which was more discriminating than yield strength and more meaningful from a metallurgical standpoint.