TIME REPORT

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Trip to:

Warren, Ohio (Meeting:
Coordination Group for
Military Handbook 5)

Duration of

Attendance:

November 10-11, 1970

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PURPOSE OF ATTENDING THE MEETING:

To represent Westinghouse and the Aerospace Industries Association.

ATTENDEES:

E. L. Layland, Westinghouse Astronuclear Laboratory

D. Shinn, AFML (Sponsor of MIL HDBK 5)

W. H. Hyler, Battelle-Columbus (Project Engineer - MIL KDBK 5)

Approximately fifty (50) members of Industry and Government Agencies

SUMMARY:

The writer attended for the first time a meeting of the Military Handbook 5 (MIL HDBK 5) Coordination Group in Warren, Ohio on November 10 & 11, 1970. This MIL HDBK is widely used by materials and design personnel in industry and in government as a source of materials properties data. It is financed by NASA and the Air Force with Mr. D. Shinn of the Air Force Materials Laboratory at Wright-Patterson AFB as Project Sponsor. Under his sponsorship, the Handbook is prepared and issued by Battelle-Columbus, with W. Hyler being the principal investigator. The following items may be of interest to you:

- 1) Carl Jaske of Battelle is studying the feasibility of statistically combining fatigue data which includes various mean stresses and various stress concentration factors. His work on 2024 aluminum alloy seems to warrant statistical treatment, and he plans to attempt such combinations with other alloys.

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- 2) Dr. David Brook of an aerospace agency in Holland gave an invited lecture on fail-safe loading of aircraft. He presented a large amount of static and cyclic strength data primarily on aluminum aircraft panels, with various thicknesses and reinforcing stringers. The stringers were of both "hat" and "Z" types, and were assembled by riveting and/or adhesive bonding. His strength data were presented as a function of crack length in each of the specimens.
- 3) C. Feddersen of Battelle discussed his proposed "Guidelines for Plane-Stress and Transitional Fracture Toughness Data Evaluation and Presentation." * This document aroused considerable opposition from the members principally because (1) his smallest cracks in the sheet plate specimens were extremely large; (2) some members believe that the residual strength of the specimens should intersect the ultimate tensile strength rather than the yield strength at "0" flaw size; and (3) the effect of thickness was not clear. Some members feel that each of his curves would apply to a narrow range of thickness because the stress intensity "K" varies with thickness.
- 4) Mr. Shinn indicated that studies are underway at General Dynamic, Boeing, Wright-Patterson AFB, and Langley to measure the fracture toughness of D6AC alloy steel used in failed components of the F-111 airplane. They will measure K_{Ic} and K_{II} as functions of heat-treating temperatures, quenching rates, and form (forgings and plate).
- 5) The Grumman representative stated that his company had decided to use fracture mechanics in the design of the F-14 fighter, particularly for components similar to those which had caused trouble on the F-111. These wing and pivot sections at Grumman have been designed with the titanium-6 aluminum-4 vanadium alloy. He presented over 300 fracture mechanics tests together with associated tensile data. He indicated that many apparent anomalies had led Grumman to conclude that fracture mechanics was not suitable by present technology for this material. Under questioning, he broadened this statement to indicate that fracture mechanics today is not suited to any material. His strong stand was based upon such factors shown by his data on this material as (1) specimens meeting the size requirements of ASTM E-24 exhibited shear in the fracture to a maximum of 50%; (2) thicker material, in general, showed higher K_{Ic} values; and (3) in the same plate, bigger specimens, more often than not, gave higher K_{Ic} values. In some cases, the smaller specimens were machined from the broken halves of larger specimens. No fracture mechanics proponents took issue with the Grumman representative, although it should be pointed out that an investigation should be conducted to understand the results that were obtained.

probably, yes — It may be that processing factors would adequately account for the results obtained. In any event, we should continue to keep abreast of the development of fracture mechanics technology and the attitudes of various users of these techniques.

The Grumman representative indicated that for fighter aircraft the cyclic crack-growth rate of materials was much more useful than K_{Ic} . He also indicated that there is no relationship between these two parameters.

5) (cont' d)

These remarks provided an invitation to the producers to combat the increasing trend toward fracture mechanics. Accordingly, the ALCOA representative stated that such experiences as cited by the Grumman representative were largely the reasons that ALCOA declines to accept specifications for aluminum alloys with fracture mechanics requirements.

The writer contacted as many of the members as possible to learn their opinions about inclusion of fracture mechanics data in MIL HDBK 5. The consensus was that the small amount of such data now in the Handbook would remain but that little, if any, new data would be added for the next revision.

- 6) Late in the afternoon of November 10, the members were assigned to ten (10) task forces to review each of the chapters for the new revision of MIL HDBK 5, which will be issued sometime next year. The next morning, each task force chairman described the changes necessary before the Handbook should be published.
- 7) Harold Blue of ANSC urged Mr. Shinn to accelerate the publishing of materials properties data. He cited the needs of the NERVA Program as an example where additional materials properties data are sorely needed.
- 8) In a private conversation, Blue asked the writer about WANL's willingness to furnish our beryllium data to MIL HDBK 5. I replied that--subject to SNPO concurrence--we would be willing to do so within a few months when our data is complete. The Brush-Beryllium representative indicated that the Hot-Pressed Block data in MIL HDBK 5 is now out-of-date.

SIGNATURE

E. L. Clayton

APPROVED

E. L. Clayton

Guidelines for Plane-Stress and Transitional
Fracture Toughness Data Evaluation and Presentation

Recent experimental observations and analytical developments indicate that the damage and fracture behavior of cracks or flaws in thin sheet (i.e., plane-stress or transitional stress state) structural configurations can be represented by a relatively simple engineering rationale. Specifically, in an ASTM Committee E-9 Symposium presentation*, which was briefly abstracted in a passout at the 39th Mil-Hdbk-5 meeting, a technique for the evaluation of crack behavior in center-crack tension panels was developed and verified. This was a phenomenological development based on experimental observations and stress intensity factor, or K concepts.

Because that procedure is linked to the concepts of linear elastic fracture mechanics, it is anticipated that this method may be complementary to the Plane-Strain Fracture Toughness (K_{Ic}) Data Screening Criteria which was approved at the 39th meeting. To this end, a proposed guidelines write-up is submitted for your consideration. It is intended to be a continuation and extension of the fracture toughness guidelines which were accepted at the last meeting, and which now exist as Sections 10.5 through 10.5.1.4.3. in the handbook. Although the testing standardization in thin sheet characterization has not been as completely and rigorously developed as in the plane-strain cases, the correlations that can be achieved are extremely good.

A basic point in the following proposal is that consistently defined and detected damage levels yield consistent K values when analyzed by this technique. The means of detection and its interpretation in structural inspection remains your choice. However, since there are several significant benchmarks of crack damage level which are of general interest and can be correlated between investigators, these are suggested for handbook presentation on a "for information only" basis at present.

*Feddersen, C. E., "Evaluation and Prediction of the Residual Strength of Center-Cracked Tension Panels", presented at the ASTM Symposium on Damage Tolerance in Aircraft Structures, Toronto, Ontario; Canada, June 23, 1970.

It should be noted that any crack behavior characterization technique must serve the dual functions of providing a comparative rating of materials, and of being expressible in the terms and dimensions of structural design. This is a fundamental reason for selecting the stress intensity factor, K , as an element in the analysis. It is a stress analysis tool and is founded in the basic mathematical concepts of elasticity.

The attached text is proposed as an addition to Chapter 10. As such it will be the foundation for data proposals to the alloy chapters of the handbook. This proposal will be considered by the Residual Strength Task Group at its meeting on October 5, 1970. At this time the item is submitted for your information and study. It will be discussed further at the 40th Committee Meeting, with consideration given for adoption.

10.5.1.5 Plane Stress and Transitional Fracture Toughness

In ductile materials and in relatively thin structural elements, the stress state may approach plane-stress conditions. Significant crack tip plasticity and stable crack growth can be manifested prior to critical fracture instability. Furthermore, due to the interaction of plasticity and geometry, the fracture toughness of a material may vary with stress state, as manifested in the thickness effect of Figure 10.5.1.3. Thus, the concept of a fixed, constant or limiting value of fracture toughness loses its meaning in this regime.

Rather, it is convenient to consider critical stress intensity factor values, varying with thickness, or stress state, as indices of crack damage resistance. The stress intensity factor can be used as a consistent measure of crack damage, not only for fracture instability, but also for other levels of crack damage severity, provided the damage is consistently specified and detected. This concept implies that the plane-stress and transitional fracture toughness of metallic materials, while not necessarily a fixed value for the material, is a characteristic constant for a given product form and thickness. This is the basis of the following guidelines.

10.5.1.5.1 Data Generation and Interpretation

Because of the complexity of crack behavior in the plane-stress and transitional stress states, test methods for evaluating material toughness have not been completely standardized; however, several useful test methods do exist. Although at the present time, each general test configuration must be interpreted and applied within its own design context, each configuration generates consistent results when the data are properly evaluated.

In the following discussion, the stress intensity factor, K , is used as a damage index. Although the K index is considered to be characteristic of a consistently specified and detected damage level, it is left unsubscripted so as not to presuppose a specific design meaning. Thus, it is a tool, and not a specification for assessing crack behavior in the materials studied.

Center Cracked Tension Panels. As a practical model which simulates real flaw conditions in thin sheet structures, the center cracked tension panel is a popular testing configuration for evaluating crack behavior. This specimen is illustrated in Figure 10.5.1.5.1 (a) along with the testing constraints necessary for useful data.

Since the stress states usually encountered with this specimen are plane-stress or transitional conditions, extensive plasticity at the crack tip as well as a slow stable growth of the crack may be exhibited under a rising load. This deviation from the abrupt fracture normally associated with crack extension in ideal plane strain conditions is illustrated in Figure 10.5.1.5.1 (b). Two limiting damage levels are noted on this figure. One, point 0, is the threshold or onset of slow, stable tear where the crack slowly extends after reaching a threshold stress level. The other, point 1, is fracture instability.

Each level of crack damage can be associated with a different stress intensity factor, or damage index, for the product forms and thicknesses of interest. These damage levels can be identified either directly with the K value as determined from the stress-crack length dimensions at those points, or approximately by the dimensions of point N. This latter point is the notch concept approach of relating the initial flaw to the fracture stress. The stress intensity factor, K, associated with any of these damage levels is computed by the general relation,

$$K = f \sqrt{\pi c} . \quad (10.5.1.5.1)$$

The locus of data points for a consistently specified damage level can be represented by parametric stress intensity factor curves, as shown in Figure 10.5.1.5.1 (c), where each curve represents a different damage level. The slow growth curve is superimposed on this figure to illustrate the general relation between threshold of stable crack extension, and fracture for a typical crack. The linear cutoff, passing through the tensile yield strength (TYS) and tangent to the K curve at two-thirds of TYS has been shown to be a consistent model of high stress-small crack behavior.

10.5.1.5.2 Criteria for Valid Data

Since precise definitions of damage mechanisms and associated instability conditions have not been adopted for crack behavior in the plane

Typical Testing Guidelines:

$$L \geq 2 W$$

$$2c_n \leq W/5 \text{ machined notch}$$

$$2c_o \leq W/4 \text{ fatigue crack sharpened notch}$$

$$S_{\text{fatigue}} \leq TYS (1-2c/W)/3 - \text{estimate only}$$

$$\dot{S} = E/12 \text{ ksi/sec} - \text{testing stress rate}$$

FIGURE 10.5.1.5.1 (a) CENTER-CRACKED TENSION PANEL TESTING CONFIGURATION

FIGURE 10.5.1.5.1 (b) CRACK GROWTH CURVE

FIGURE 10.5.1.5.1 (c) PARAMETRIC STRESS INTENSITY FACTOR CURVES
AS INDICES OF CRACK DAMAGE

stress and transition stress states, only general constraints can be suggested for screening data. The basic criterion to assure that crack damage or fracture instability occurs under predominantly linear elastic conditions is that the net section stress be less than the tensile yield strength (TYS). This can be further constrained by other stress and boundary restrictions on the specific specimen configurations.

Center Cracked Tension Panels. The data which are derived from center-cracked tension panel tests are screened by two criteria to assure that crack behavior is primarily elastic. The stress limit

$$f \leq \frac{2}{3} \text{ TYS}, \quad (10.5.1.5.2 \text{ (a)})$$

is used to suppress plasticity effects; the crack size criterion,

$$2c \leq W/3, \quad (10.5.1.5/2 \text{ (b)})$$

is used to limit panel boundary influences. The data which satisfy these criteria may be used in Expression 10.5.1.5.1 to compute a characteristic damage index.

10.5.1.5.3 Data Presentation

Plane stress and transitional fracture toughness data and other crack damage information are presented in the opening discussion of each alloy chapter in Mil-Hdbk-5 where such data are available. The data are categorized by product form and thickness (or thickness range). The presentation format is dependent upon the flaw and structural configuration as described in the following paragraphs.

Center Cracked Tension Panel Data. These data are presented on a graphical format of stress versus crack length. A typical data display format is illustrated in Figure 10.5.1.5.3. Three basic measures of crack damage are presented. The upper curve denotes approximate fracture instability; the lower curve denotes the approximate threshold or onset stable tear or crack extension during the rising load test. The intermediate curve represents the notch analysis concept or locus of data points "N" as noted on Figure 10.5.1.5.1 (b).

The K value which is associated with each curve is a simple average of the data which satisfy the screening criteria of Expressions 10.5.1.5.2 (a) and (b). Although some data points will be shown above the stress limit, they are included only to demonstrate the adequacy of the linear curve fit to the limiting stress value of TYS.

FIGURE 10.5.1.5.3 FORMAT FOR THE PRESENTATION OF CENTER-CRACKED TENSION PANEL DATA