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FRACTURE MECHANICS TESTING CAPABILITY

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Project Leader:
M. G. Ulitchny
Department 814

Project Team:
D. C. Dyer
M. C. Collins
F. E. Lormis
G. D. Swanson
C. E. Watterson

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FRACTURE MECHANICS TESTING CAPABILITY

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September 1976

Prepared by M. G. Ulitchny, D/814, under PDO 6985028

The Metal Diagnostics and Physics section of the Materials Evaluation Laboratory, Bendix Kansas City, has established a fracture mechanics testing capability. Included is the capability to perform fracture toughness (both static and dynamic), fatigue, J-integral, and notch sensitivity tests.

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THE BENDIX CORPORATION
KANSAS CITY DIVISION
P.O. BOX 1159
KANSAS CITY, MISSOURI 64141

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SUMMARY

In order to support fracture resistance requirements on high strength materials, the Metal Diagnostics and Physics section of the Materials Evaluation Laboratory, Bendix Kansas City, has established a fracture mechanics testing capability. Included are the capability to perform fracture toughness (both static and dynamic), fatigue, J-integral, and notch sensitivity tests.

Equipment needs and specifications were defined under an earlier short term Process Development Order (PDO 6989242), *Fracture Toughness of High Strength Steel*. The results of that study indicated two basic sets of equipment should be acquired: a dynamic universal testing machine which could perform static fracture toughness, J-integral, fatigue, and notch sensitivity tests; and an instrumentation package to modify an existing impact tester. This equipment can provide dynamic fracture toughness data as well as a faster, less expensive screening technique. A specimen precracker along with the instrumentation package was also required.

Under a capital equipment appropriation set up to support a process development endeavor these two sets of test equipment have been ordered, received, and installed. These facilities and the associated fracture mechanics tests are described.

DISCUSSION

SCOPE AND PURPOSE

The capacity to perform various fracture mechanics tests on high strength-high toughness materials has been established in the Metal Diagnostics and Physics section of the Materials Evaluation Laboratory. Static and dynamic fracture toughness, fatigue, J-integral, and notch sensitivity tests can now be performed at this facility. The test equipment described in this report was required to support planned material evaluations and to support fracture mechanics requirements foreseen on future programs.

PRIOR WORK

Bendix Kansas City has not had extensive experience in the fracture mechanics testing of high strength-high toughness materials. Prior experience involving similar testing was gained on alumina substrates used in hybrid microcircuits and chemical vapor deposited tungsten and tungsten-rhenium alloys. In view of fracture toughness requirements for certain high strength materials, a short term process development project *Fracture Toughness of High Strength Steel* (6989242) was initiated to identify equipment needs and specifications required to perform these tests. The equipment requirements were incorporated into a capital equipment appropriation, Number 17526, which was approved for the purchase.

ACTIVITY

MTS Dynamic Test System

The MTS Systems Corporation, Model 810.13 Material Test System is a servohydraulic dynamic mechanical test machine capable of operating at loads up to 56,000 lbf (250 kN), actuator strokes of up to 5 inches (125 mm), and frequencies of up to 100 Hz. The loads can range from full tension to full compression at the rated capacity.

Figure 1 shows the working areas of the load frame and control units in an actual fracture mechanics testing configuration. Tests are controlled by a function generator that provides the capability to apply loads in sine wave, square wave, or a variety of ramp function modes. These loads can be applied between any two preselected points from full tension to full compression at frequencies ranging from 0.0001 to 100 Hz. Simple tension or compression tests can be controlled by the same function generator.

Figure 1. MTS Load Frame and Control Console

Tests can be controlled in any of three ways--load control, stroke control, or strain control. A digital counter is also included which allows for stopping cyclic tests automatically when a preset number of cycles has been reached. Data from higher frequency cyclic tests can be monitored on a standard oscilloscope, while data from slower tests can be displayed on an X-Y recorder.

Figure 2 shows a close-up view of a compact tension fracture toughness test specimen in place and ready to be tested according to ASTM Standard Test Method E399. The 250 kN load cell, hydraulic actuator, crack opening displacement (COD) gage, and fracture mechanics grips can be clearly seen.

Figure 2. Compact Tension Fracture Toughness Test Specimen and COD Gage

Subsequent to the receipt and installation of this equipment, a series of tests were run to check out the equipment and to prove-in testing techniques. The MTS unit was checked using 6061-T6 aluminum compact tension fracture toughness samples (Figure 2) with a specimen thickness of 2.00 inches (50.8 mm) as defined in ASTM Standard Test Method E399.

For the compact tension tests performed on the MTS equipment, the specimen is loaded into the clevis type grips and the clip gage is attached (Figure 2). The sample was then fatigue precracked to the requirements of ASTM E399. For the present case, this amounted to preloading the specimen to 560 pounds (2.5 kN) and then cycling between 560 and 10,000 pounds (2.5 and 45 kN) at 15 Hz, using sinusoidal loading. The small preload prevents complete unloading of the load train thereby avoiding mechanical peening of the fixtures and specimen. The crack growth, observed by a telescope, is continued until it reaches a depth of 45 to 55 percent of the specimen depth. It took 21,400 cycles to precrack this sample. After precracking, the sample was then ready to break in a pull test. Although not required by ASTM E399, a series of compliance curves were run at different stages of the precracking. This technique will be useful when doing J-integral testing with this equipment or in later automatic control of precracking. These compliance curves are shown in Figure 3. Curve 1, Figure 3, was made before precracking started, while Curve 6 was made just before the pull test. Table 1 shows a legend of conditions for the various curves. A relationship between compliance and crack length can be determined thus making the compliance a direct measure of crack length.

A straight ramp function pull test was then run on the compact tension specimens. Figure 4 shows the test tract of load versus displacement. The loading rate is determined according to ASTM E399. The stress intensity value (K_Q) for this particular sample was calculated to be $40.3 \text{ ksi} \cdot \text{in.}^{\frac{1}{2}}$ ($44.3 \text{ MPa} \cdot \text{m}^{\frac{1}{2}}$). Although these samples did not give valid fracture toughness values (K_{IC}) because their section thickness did not meet the requirement of Section 9.1.5 of ASTM E399, the operating techniques used to run this prove-in test were exactly the same as those used to run any valid fracture toughness test. Many of these same procedures would also be used in fatigue or J-integral tests.

Instrumented Charpy Impact Tests

The Effects Technology Incorporated, Model 500 Dynatup instrumentation package is a system that can be interfaced with a conventional Charpy impact test machine to monitor the dynamic behavior of the specimen during impact. This instrumentation supplies a precise analog signal of the specimen's load-time and energy-time history. These data are used to analyze the dynamic fracture toughness as well as other important dynamic mechanical properties of the material.

Figure 3. Compliance Curves for Compact Tension Sample of 6061-T6 Aluminum

Figure 4. Fracture Toughness Test Curve for Compact Tension Sample of 6061-T6 Aluminum

Table 1. Legend for Compliance
Curves Shown in
Figure 3

Curve Number	Approximate Crack Depth (Percent)
1	Uncracked
2	45.5
3	46.0
4	48.5
5	50.8
6	55

Figure 5 shows the Dynatup system mounted on an existing Tinius-Olson impact tester. This tester has 264 foot-pound-force (358 J) and 120 foot-pound-force (163 J) ranges. The striker head of the impact tester has been strain gaged and calibrated as a part of the Dynatup package. The electronic control unit located on top of the impact tester is called the dynamic response module. This unit conditions the signal from the strain gages on the striker at impact so that a load-time trace is displayed on one beam of the dual-beam storage oscilloscope. At the same time, this signal is integrated, giving a second signal proportional to the energy absorbed during the impact loading of the test piece. This energy-time signal is recorded as the second trace on the oscilloscope. These traces then provide the data record for each test.

In addition, the Dynatup system features a light beam-grid interrupt device mounted partly on the striker frame and partly on the sample holder of the tester. This device provides a signal that can be used either to measure the velocity of the striker or to trigger the dynamic response module for a test.

For measurements of dynamic fracture toughness of many materials, it is necessary to have a precracked Charpy test sample, so a Dynatup Research Model B precracker is included as a part of this package (Figure 6). This device allows up to eight Charpy samples to be fatigue precracked simultaneously at rates of 11.7, 23.4, or 35.1 Hz. Individual loading bolts allow separate stress intensity levels to be selected for each sample during precracking. An automatic timer is used to control stages of precracking to assure proper precrack depths.

Figure 5. Instrumented Charpy Impact Tester

Figure 6. Dynatup Research Model B Precracker for Charpy Test Specimens

Following installation, the Effects Technology equipment was checked out using 6061-T651 aluminum Charpy impact test specimens defined in ASTM Standard Test Method E23. Standard Charpy V-notch specimens were used to check out the Dynatup Model 500 Charpy instrumentation package. Samples of 6061-T651 aluminum alloy were selected because vendor provided data could be compared to our results. The samples were broken, utilizing standard impact test techniques. The load versus time and energy versus time data were displayed on the dual beam storage oscilloscope. Figure 7 shows a typical trace from one of these samples. The load curve peaked at about 1550 pounds (6.9 kN) after about 240 microseconds. The energy curve leveled off at about 7.5 foot-pound-force (10.2 J), compared to a reading of about 7 foot-pound-force (9.5 J) from the impact tester's energy dial. These loads and energies agree completely with values provided by the vendor. The perturbations seen in the load trace are oscillations of the striker caused by reflections of the stress waves, and are not perturbations in the test sample behavior.

Figure 8 shows a trace from the light beam interrupt system on the striker. This trace indicates an initial striker velocity of 11.4 foot-seconds (3.47 m/s) at the point of impact which is well within the recommended working range of the Effects Technology equipment.

ACCOMPLISHMENTS

A fracture mechanics testing capability has been procured and checked out in the Materials Evaluation Laboratory. This new facility includes the capability to perform static and dynamic fracture toughness, fatigue, J-integral and notch sensitivity tests. Most operating procedures have been established for the MTS Dynamic Test System and the Dynatup Model Instrumented Charpy Tester. Bendix personnel are performing tests required to support process development.

Figure 7. Instrumented Charpy Test Traces

Figure 8. Velocity Trace-Impact Striker

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