MICROTEK
LABORATORIES

# Fracture Toughness

Critical Stress - Resistance - Testing

## Plane-Strain Fracture Toughness and Strain Energy Release Rate of Composite and Plastic Materials:

### ASTM D5045

Fracture toughness is a property which describes the ability of a material containing a crack to resist fracture, and is one of the most important properties of any material for virtually all design applications. Test methods such as ASTM D5045 are designed to characterize the toughness of composites and plastics in terms of the critical-stress-intensity factor, $K_{IC}$, and the energy per unit area of crack surface or critical strain energy release rate, $G_{IC}$, at fracture initiation.

Fracture toughness is a quantitative way of expressing a material's resistance to brittle fracture when a crack is present. If a material has a large value of fracture toughness it will probably undergo ductile fracture. Brittle fracture is very characteristic of materials with a low fracture toughness value. Fracture toughness is an indication of the amount of stress required to propagate a preexisting flaw. It is a very important material property since the occurrence of flaws is not completely avoidable in the processing, fabrication, or service of a material/component. Flaws may appear as cracks, voids, metallurgical inclusions, weld defects, design discontinuities, or some combination thereof. Since engineers can never be totally sure that a material is flaw free, it is common practice to assume that a flaw of some chosen size will be present in some number of components and use the linear elastic fracture mechanics (LEFM) approach to design critical components. This approach uses the flaw size and features, component geometry, loading conditions and the material property called fracture toughness to evaluate the ability of a component containing a flaw to resist fracture. A parameter called the stress-intensity factor (K) is used to determine the fracture toughness of most materials. A Roman numeral subscript indicates the mode of fracture and the three modes of fracture are illustrated in the image to the right. Mode I fracture is the condition in which the crack plane is normal to the direction of largest tensile loading. This is the most commonly encountered mode and, therefore, for the remainder of the material we will consider $K_I$.

The stress intensity factor is a function of loading, crack size, and structural geometry. The stress intensity factor may be represented by the following equation:

$$K_I = \sigma\sqrt{\pi a \beta}$$

Where: $K_I$ is the fracture toughness in $MPa\sqrt{m}$ $(psi\sqrt{in})$

s is the applied stress in MPa or psi

a is the crack length in meters or inches

B is a crack length and component geometry factor that is different for each specimen and is dimensionless.

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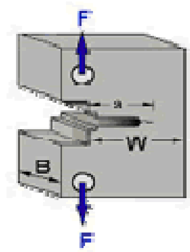
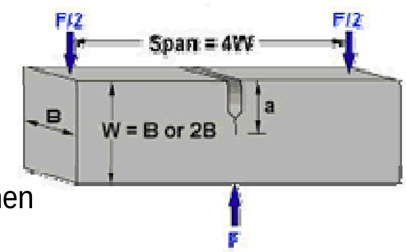



CT Specimen




SENB Specimen

## Plane-Strain Fracture Toughness Testing

When performing a fracture toughness test, the most common test specimen configurations are the single edge notch bend (SENB or three-point bend), and the compact tension (CT) specimens.

| | | |
|---|---|---|
| Where: | B | is the minimum thickness that produces a condition where plastic strain energy at the crack tip in minimal |
| | $K_{IC}$ | is the fracture toughness of the material |
| | $s_y$ | is the yield stress of material |

When a material of unknown fracture toughness is tested, a specimen of full material section thickness is tested or the specimen is sized based on a prediction of the fracture toughness. If the fracture toughness value resulting from the test does not satisfy the requirement of the above equation, the test must be repeated using a thicker specimen. In addition to this thickness calculation, test specifications have several other requirements that must be met (such as the size of the shear lips) before a test can be said to have resulted in a $K_{IC}$ value.
When a test fails to meet the thickness and other test requirement that are in place to insure plane-strain condition, the fracture toughness values produced is given the designation $K_C$. Sometimes it is not possible to produce a specimen that meets the thickness requirement. For example when a relatively thin plate product with high toughness is being tested, it might not be possible to produce a thicker specimen with plain-strain conditions at the crack tip.

## Plane-Stress and Transitional-Stress States

For cases where the plastic energy at the crack tip is not negligible, other fracture mechanics parameters, such as the J integral or R-curve, can be used to characterize a material. The toughness data produced by these other tests will be dependent on the thickness of the product tested and will not be a true material property. However, plane-strain conditions do not exist in all structural configurations and using $K_{IC}$ values in the design of relatively thin areas may result in excess conservatism and a weight or cost penalty. In cases where the actual stress state is plane-stress or, more generally, some intermediate- or transitional-stress state, it is more appropriate to use J integral or R-curve data, which account for slow, stable fracture (ductile tearing) rather than rapid (brittle) fracture.

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### Uses of Plane-Strain Fracture Toughness

$K_{IC}$ values are used to determine the critical crack length when a given stress is applied to a component.

$$\sigma_C \leq \frac{K_{IC}}{Y\sqrt{\pi a}}$$

Where: $s_C$ is the critical applied stress that will cause failure

$K_{IC}$ is the plane-strain fracture toughness

Y is a constant related to the sample's geometry

a is the crack length for edge cracks or one half crack length for internal crack

$K_{IC}$ values are used also used to calculate the critical stress value when a crack of a given length is found in a component.

$$a_c = \frac{1}{\pi}\left(\frac{K_{IC}}{\sigma Y}\right)^2$$

Where: a is the crack length for edge cracks or one half crack length for internal crack

s is the stress applied to the material

$K_{IC}$ is the plane-strain fracture toughness

Y is a constant related to the sample's geometry

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