What is the difference between strength and toughness?

For structural components, strength and fracture toughness are two important mechanical properties. Yield strength is the measure of the stress that a metal can withstand before deforming. Tensile strength is a measure of the maximum stress that a metal can support before starting to fracture. Fracture toughness is a measure of the energy required to fracture a material that contains a crack.

As the yield strength increases, the amount of stress a metal can support without deforming increases. Alternatively, as yield strength increases, a smaller cross-section of metal is required to support a given load without deforming. As tensile strength increases, the amount of stress a metal can support without cracking and fracturing increases. And as fracture toughness increases, the energy required to cause a crack to grow to fracture increases. Low fracture toughness corresponds to low ductility. For example, glass has very low toughness and is very brittle.

For a component with a crack of a particular length, as the fracture toughness decreases there is a decrease in the component’s ability to withstand its load before fracturing. Conversely, for a certain load, as the fracture toughness increases, a component can tolerate a longer crack before fracturing.

As shown in the figure, for any particular alloy, toughness decreases as strength increases. Consequently, when high toughness and high strength are both required it is often necessary to change from one alloy to a different alloy that satisfies both requirements.

Designers are often tempted to use a material that is as strong as possible to enable them to minimize component cross-section. However, this can inadvertently lead to using a material with insufficient fracture toughness to withstand fracturing if a small crack forms in the material during component manufacturing or during use.

Fatigue stress is also another cause of cracks. The formation of cracks in components exposed to fatigue conditions is often expected. In these situations, knowledge of the fracture toughness is required to determine how long the component can remain in service before a crack grows so long that the intact cross-section of the component cannot support the load, and the component fractures. This applies to aerospace components and pressure vessels such as boilers.
For structural components exposed to fatigue conditions, designers must be concerned with both the strength and the toughness. The strength must be large enough so that the material can withstand the applied loads without deforming. The toughness must be sufficient for the metal to withstand the formation of fatigue cracks without failing catastrophically.


I hope this article was helpful. However, if you still have a specific metallurgy question that was not addressed, I offer a 15-minute phone consultation for $60. I’ve found that many questions can be answered in 15 minutes, helping to get people back on track. Here’s the link to purchase the consultation [http://www.imetllc.com/metallurgy-consultation/](http://www.imetllc.com/metallurgy-consultation/).

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