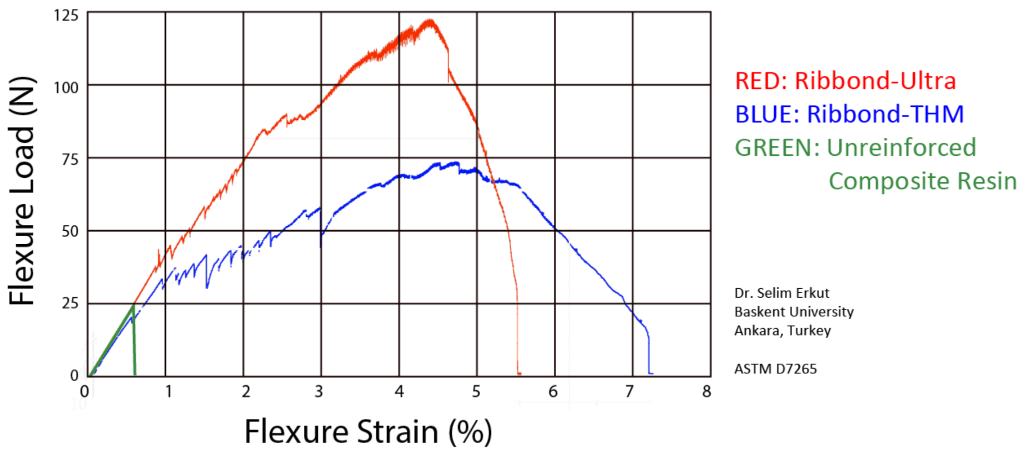
HOW TO EVALUATE STRENGTH FOR DENTAL FIBER REINFORCEMENTS

Be cautious when trying to use strength tests to predict clinical performance. There are many different qualities of strength. If we are to use a specific quality of strength to try to predict clinical success we must first understand how that particular strength quality relates to clinical performance. To define strength we will also need to define clinical failure. For example; if a chain is only as strong as its weakest link, it would make sense to test for a chain's weakest link rather than for its strongest link.

One of the world's foremost recognized material scientists was J.E Gordon. J.E. Gordon wrote in his book *The new Science Of Strong Materials*: "The worst sin in an engineering material is not a lack of strength or lack of stiffness, desired as these properties are, but lack of toughness, that is to say, lack of resistance to the propagation of cracks". In other words, materials tend to fail not for a lack of flexural strength or stiffness but rather for a lack of fracture toughness.

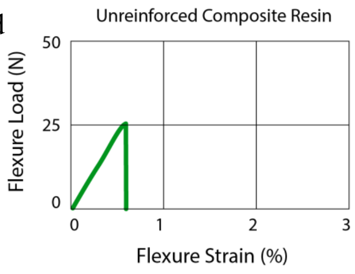
When evaluating a material's strength, the dental industry traditionally has relied on flexural strength and flexural modulus tests. However, as J.E. Gordon suggests, the mode of failure would not be lack of flexural strength but rather a lack of fracture toughness. Therefore, if a material fails because its "weakest link" is a lack of fracture toughness instead of a lack of flexural strength, then shouldn't we test for a materials fracture toughness rather than flexural strength? This document describes how to evaluate the fracture toughness of a fiber reinforcement material. It concludes by describing performance advantages of the Ribbond-Ultra versus the Ribbond-THM and the Ribbond-Original.



Dr. Selim Erkut
Baskent University
Ankara, Turkey

ASTM D7265

The above graph shows results of four-point stress-strain tests for unreinforced composite resin, composite resin reinforced with Ribbond-Ultra, and composite resin reinforced with Ribbond-THM.   Dentists are probably not accustomed to seeing graphs like this with jagged curves. The jagged steps in the Ribbond-Ultra and Ribbond-THM graph curves represent small cracking events in which a crack starts and travels a short distance but is stopped by the unique nodal intersections of the patented Ribbond leno woven fibers. The performance characteristics in this study for the fiber reinforced test bars are specific to the leno woven Ribbond products. Glass and quartz fiber materials will not be as effective in preventing crack propagation and will behave more like a brittle material.



Dentists are accustomed to seeing a stress-strain curve similar to the green curve in this graph. This is standard curve for a brittle material, which in this case it is an unreinforced dental composite resin. The curve angles upward in a uniformly straight line until it reaches its breaking point and catastrophic fracture failure occurs. This indicates that a crack began in the brittle composite resin; it then reached a critical length and then propagated rapidly causing catastrophic failure.

IN-VITRO FLEXURAL MODULUS TERSTING OF FIBERS LACKS CLINICAL RELEVANCE

Stiff materials are frequently brittle and are not fracture tough. Glass in both bulk and fiber form is a good example of a material that is generally considered stiff but is also brittle. Glass fibers reinforcements can demonstrate relatively high flexural modulus in in-vitro material tests but when used to make a structure it is its lack of fracture toughness that will likely lead to its failure.

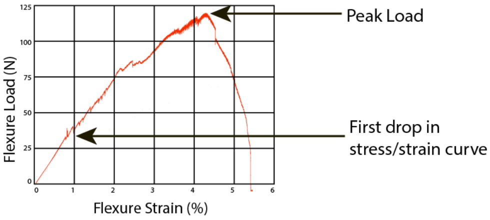
As J.E. Gordon knew and as all structural engineers know, <u>it is much easier to design a structure for stiffness using non-stiff materials than it is to design a structure for fracture toughness when using non-fracture tough materials.</u> Stiffness can be created by placing non-stiff fibers in such a way to form a fiber-composite laminate structure. An example of a fiber-composite laminate is the close bonding of the fibers against the surfaces of the teeth. The closer the fibers are bonded to the teeth, the thinner the bondline will be and the better the laminate effect will be. Another example is using multiple layers of fibers to make a fiber-composite laminate beam in an edentulous area.

In-vitro strength testing of materials does not necessarily account for how materials perform when used to make a structure. In the case of fiber reinforcements, manageability of the fibers will greatly influence the material's ability to follow intricate contours to construct effective laminate structures. Materials with poor manageability qualities will result in thicker bond lines and will not allow for the construction of effective laminate structures. We argue that glass fibers have more memory than the Ribbond fibers and therefore will not make as effective laminate structures as Ribbond.

FLEXURAL STRENGTH

Flexural strength is the load/stress required to fracture a material from bending forces. There is no universal definition for how to determine the point of failure in a flexural strength test. For example, some flexural strength tests define failure until there is a there is a drop in the stress/strain curve. Other protocols define failure at the peak load prior to 5% distortion (strain) of the test specimen.

Initial Cracking Episode Vs. Peak Load



If a traditional dental flexural strength test defines flexural strength as the point when the stress/strain curve <u>first drops</u>, then the flexural strength of the Ribbond-Ultra reinforced test bar would register at approximately 32 Newtons (N). This drop in the stress/strain curve is associated with the first cracking event in the material. However, something much more relevant happens after these initial cracking events occur. These traditional flexural strength test protocols do not tell the whole story. As this graph shows, the Ribbond-Ultra test bars are actually functioning well past these first cracking events and continue to function to a peak load of approximately 120 N.

The flexural strength of the Ribbond-Ultra reached its peak load of approximately 120 N at 4.4% flexural strain. 4.4% strain is within a range in which most people will consider the prosthesis to still be functioning at an acceptable level of service (see the *Defining Clinical Failure* section of this document on the bottom of page 4).

FRACTURE TOUGHNESS

The continuing function of the Ribbond reinforced test samples after multiple cracking events is due to the strength quality known as fracture toughness. Ribbond provides fracture toughness to the fiber-composite structure. Fiber-composite scientists and teachers (such as J.E. Gordon) consider fracture toughness a more accurate indicator of a fiber reinforcement's industrial performance than flexural strength or flexural modulus.

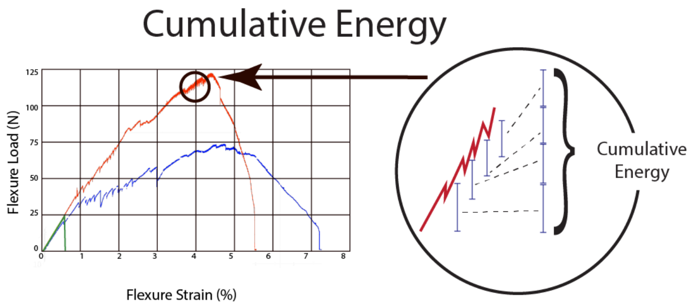
Fracture toughness is a material's ability to maintain structural integrity despite damage from cracking. By stopping catastrophic crack propagation, the integrity of the material is maintained and it continues to function and is still clinically serviceable.

Fracture toughness is not a term that is commonly used in dentistry but it is a term that we instinctively are aware of. A very common example of a fracture tough material is wood. Wood has lots of cracks in it but the existence of cracks generally does not cause the wood to fail catastrophically. Another example of a fracture tough material is teeth. Many teeth have cracks. However, the existence of a crack does not necessarily mean that the crack has propagated to a point in which the tooth catastrophically fails.

ENERGY ABSORPTION

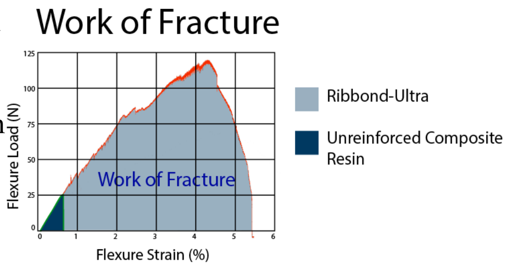
A fracture tough material is able to withstand damage and not fail catastrophically. More and more energy is required to cause continued crack propagation. This fracture toughness is represented by the jagged steps in the curves in the Ribbond reinforced test bars. Starting a crack requires energy and every "up-tic" in the jagged lines shown in this graph represents the energy being consumed to start a new crack. The individual cracking events are arrested and stopped at the tough Ribbond fiber nodal intersections.

If we look closer at the top of the curve for the Ribbond-Ultra, we can see a close grouping of these cracking events. The amount of energy required to ultimately lead to failure is not at the peak of the curve (approximately 120 Newtons), but actually is the total combined energy measured by the cumulative lengths of the "up-tics" in the curve. Traditional flexural strength test protocols do not account for this cumulative energy phenomenon when testing fracture tough fiber reinforcement materials.



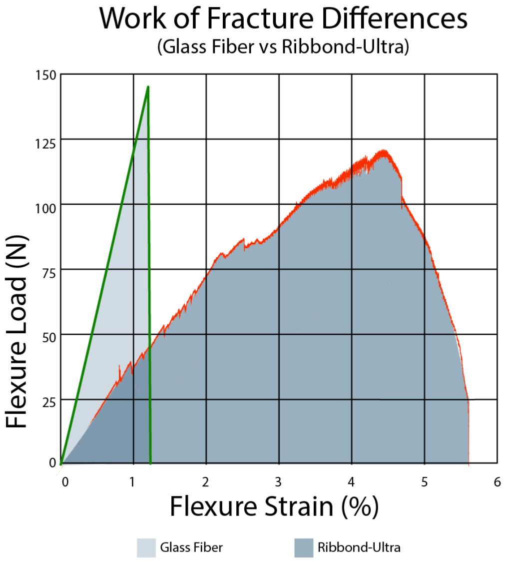
WORK OF FRACTURE

An important criterion in materials science is *work of fracture*. Work of fracture is how much work/energy is required to fracture a material. The area under the stress strain curve represents the amount of work/energy that it takes to fracture the material. You can see that the work of fracture for the Ribbond-Ultra reinforced test bars (the gross area under the curve) is exponentially higher than that of the unreinforced composite resin test bars.



This graph shows a relatively high hypothetical flexural strength curve for a unidirectional glass fiber reinforcement compared to the Ribbond-Ultra flexural strength curve. Relative to an unreinforced composite resin, the glass fibers will increase the flexural strength and can even increase the flexural modulus. The glass fiber reinforcements might even demonstrate higher flexural strength than the Ribbond-Ultra. However, like a brittle material, when glass fiber reinforcements fail they tend to fail catastrophically.

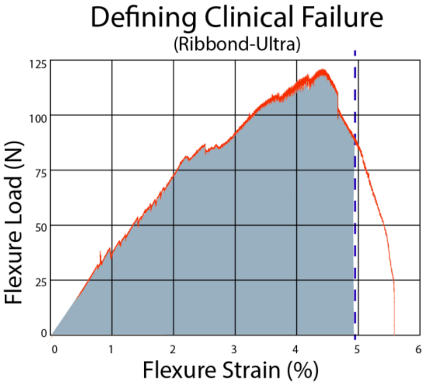
As this graph shows, just because a material might have higher flexural strength and possibly also have a higher flexural modulus than another material, these higher strength values do not necessarily relate to greater structural success. The gross area (work of fracture) under the Ribbond-Ultra curve is far greater than the gross area (work of fracture) under the typical unidirectional glass fiber curve. This indicates that the Ribbond-Ultra is much more fracture tough. J.E. Gordon would likely say that in this case the material with the lower flexural strength (the Ribbond-Ultra) would demonstrate greater long-term clinical performance than the glass fiber reinforcement because it is more fracture tough.



Be cautious when trying to use strength tests to predict clinical performance…

CLINICAL SIGNIFICANCE: DEFINING CLINICAL FAILURE IN A FRACTURE TOUGH MATERIAL

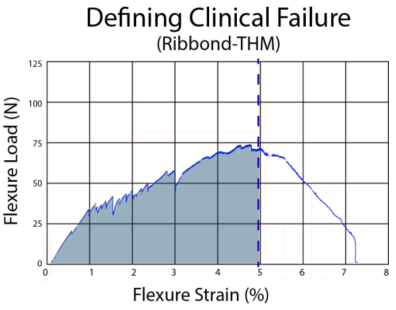
A well designed fiber reinforced dental prostheses/application will continue to function past its peak load. It functions adequately until it bends to a degree that is past its acceptable level of performance. Each clinical case is different and how and when the dentist or the patient might define failure due to structural distortion is case specific. The degree of structural distortion in one case might have a different definition of clinical effectiveness than another.



This graph has the parts of the “tails” of the stress-strain curves deleted indicating a hypothetical point in which someone might consider that the structure to be past the acceptable level of service due to bending. At this point the work of fracture could be defined by measuring the gross area under the particular stress/strain curve.

The fracture tough material might have already reached its peak load but clinically the fracture tough material might still be clinically serviceable despite already passing its peak load. Traditional flexural test protocols do not account for this phenomenon either.

This graph shows the work of fracture (gross area under the curve) for the Ribbond-THM.

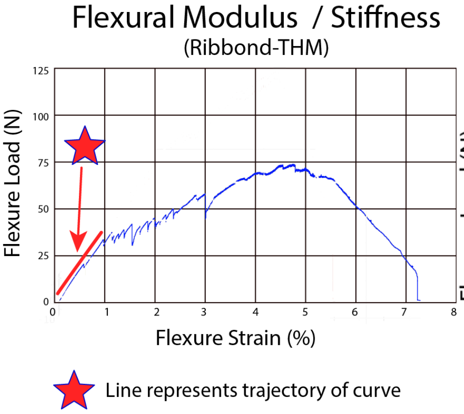

Defining Clinical Failure
(Ribbond-THM)

ADVANTAGES OF RIBBOND-ULTRA VERSUS RIBBOND-THM AND RIBBOND-ORIGINAL

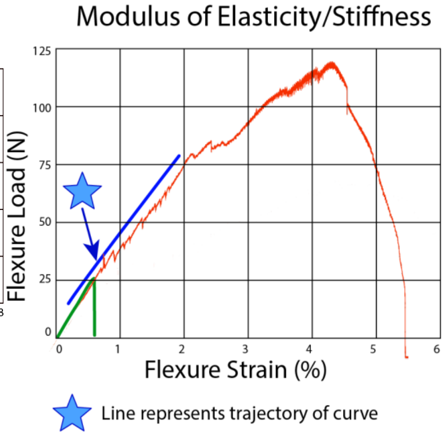
Although fracture toughness is more important to fiber composite scientists than flexural strength and flexural modulus, this does not mean that these characteristics are not desirable.

Flexural modulus is a measure of stiffness, which means the material's resistance to bending. Or to phrase this a different way, its rate of bending.

The Ribbond-Ultra was designed so that it is both stiff <u>and</u> fracture tough. The trajectory of the Ribbond-Ultra curve is relatively straight and follows a similar curve (or rate of bending) as the brittle unreinforced composite. This indicates a flexural modulus similar to that of the unreinforced composite samples. The unreinforced composite resin fractured at 30 N. The Ribbond-Ultra curve remains relatively straight until it reached a load of 85 N before its rate of bending significantly changes. Although its rate of bending changed at 85 N for the Ribbond-Ultra, the curve still maintained a general upward trajectory and peaked at approximately 120 N at 4.4% strain.


Flexural Modulus / Stiffness
(Ribbond-THM)

★ Line represents trajectory of curve

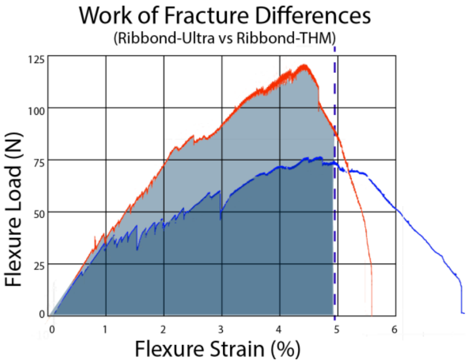

Modulus of Elasticity/Stiffness

★ Line represents trajectory of curve

The Ribbond-THM shares a similar flexural modulus until approximately 34 N until its general curve direction significantly changes.

Although the Ribbond-Original was not included in these tests, it would have exhibited lower flexural modulus and a lower flexural strength as well. Like the other Ribbond products, the Ribbond-Original would have shown significantly higher fracture toughness values than the unreinforced test bars.

Ribbond-Ultra has a higher flexural modulus than the Ribbond-THM and Ribbond-Original. Ribbond-Ultra's peak load is much higher than the Ribbond-THM and Ribbond-Original. More significantly, if we measure the gross area under the curves at the peak loads, the Ribbond-Ultra has a greater area, which suggests it provides greater work of fracture as well.


Work of Fracture Differences
(Ribbond-Ultra vs Ribbond-THM)

Other benefits to the Ribbond-Ultra is that it is thinner and more comfortable for the patient and has better manageability characteristics. Being more manageable allows it to more closely follow the contours of the teeth, which leads to thinner bond lines and better laminate effects.