

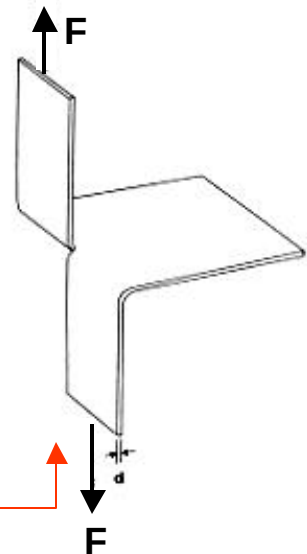
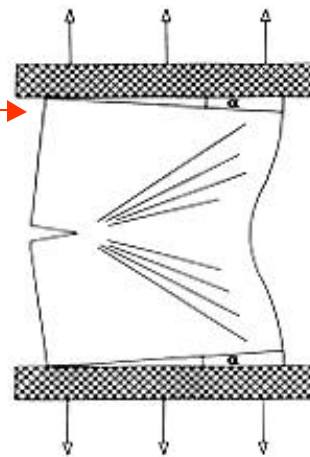
Tear Strength

- Tearing resistance is the **total energy per tear length** consumed when a specimen of a given geometry undergoes **tearing**.

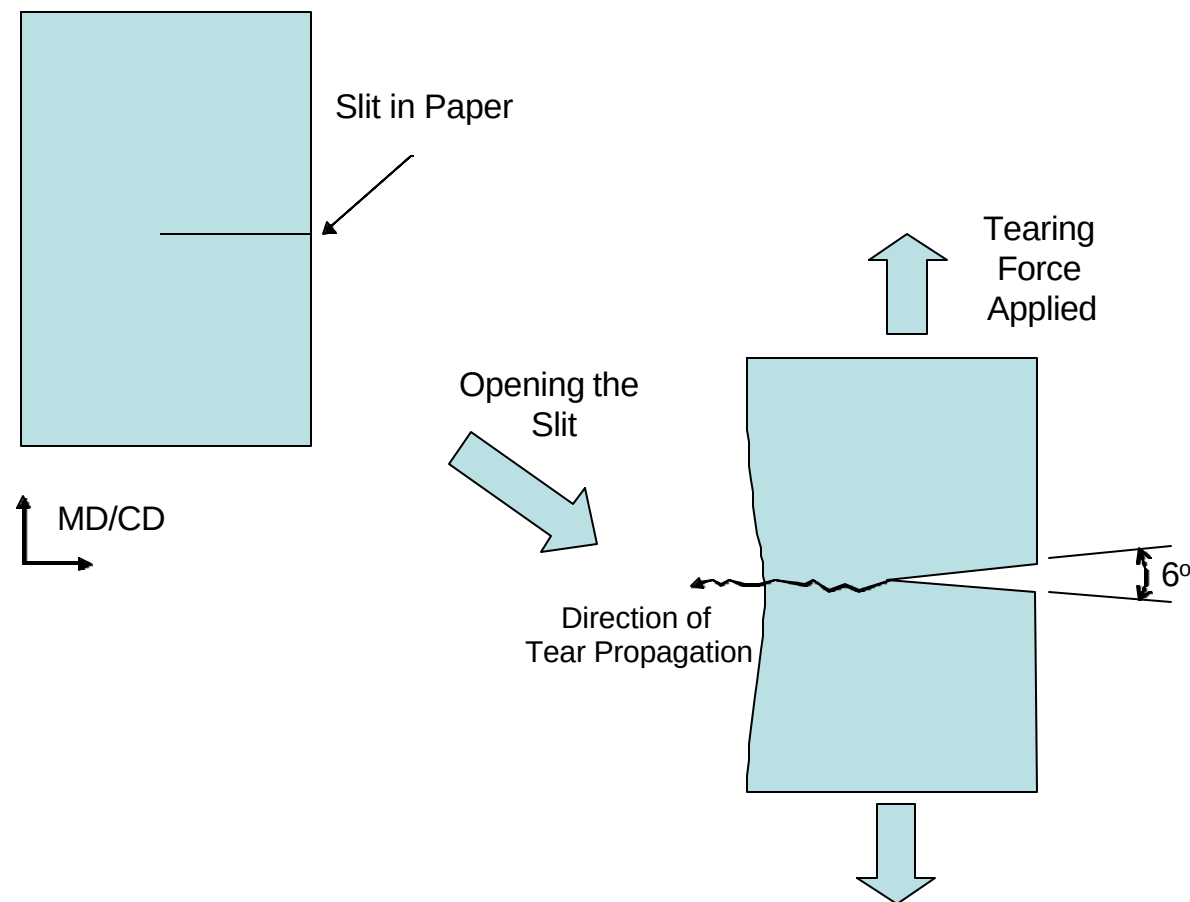
Two Types of Tear Tests:

(1) **In-plane** Tear

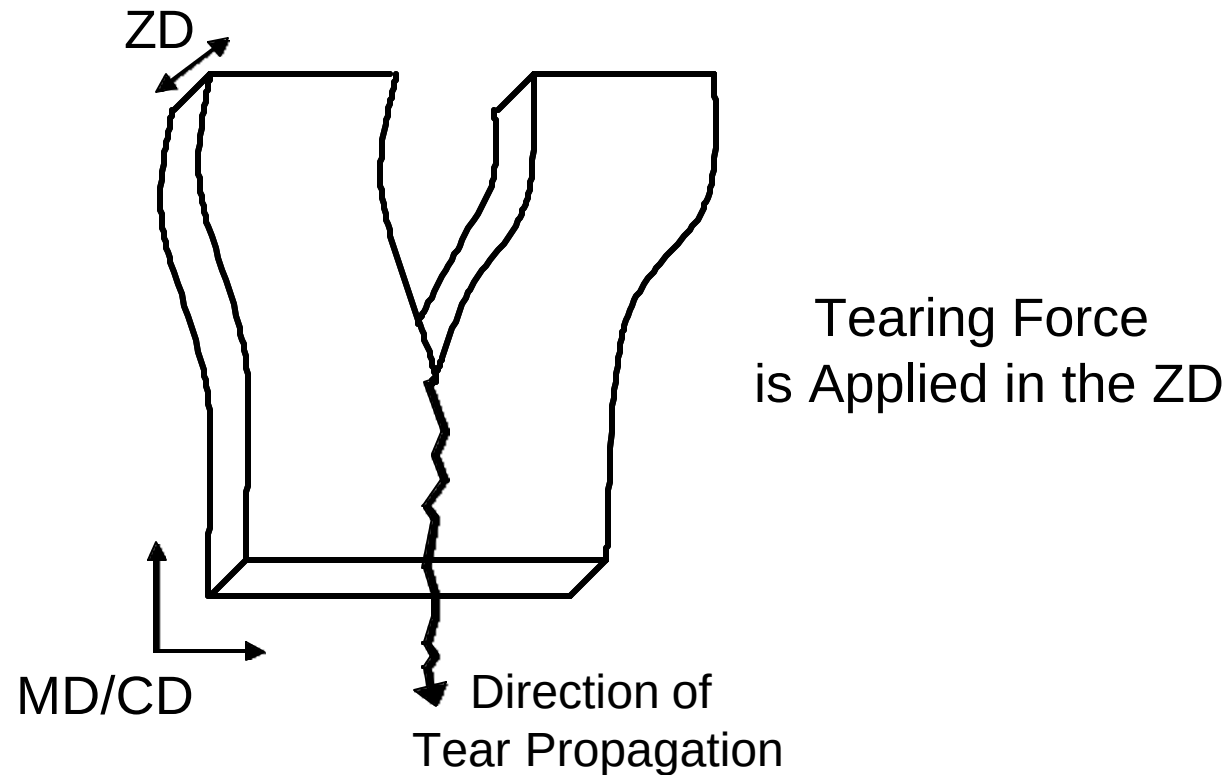
(2) **Out-of-plane** Tear



(1) **In-plane Tear** – A tear test in which the tearing force is applied to the sheet in a manner **similar to a tensile test**. A tear is initiated (i.e. a slit is put in the sheet), the slit is then opened a certain amount and a tearing force is applied. The work required to tear the sheet is then recorded.



(2) **Out-of-plane Tear** – A tear test in which the **force is applied to the sheet perpendicular to the plane** of the sheet (ex. Elmendorf tear – the test performed in lab). A slit is put into the sheet, then the work required to tear the sheet is measured.



Tearing resistance, has the units of load and is sometimes called **tear strength**, although **it is energy not stress** that is measured.

Factors Affecting the Tear Strength

The tear strength is a measure of the amount of work required to tear the sheet. Therefore, **sheet structures that dissipate energy have higher tear strengths.**

When a **crack propagates** in the fiber network, at least **four mechanisms of energy dissipation** operate at the fiber level. These include:

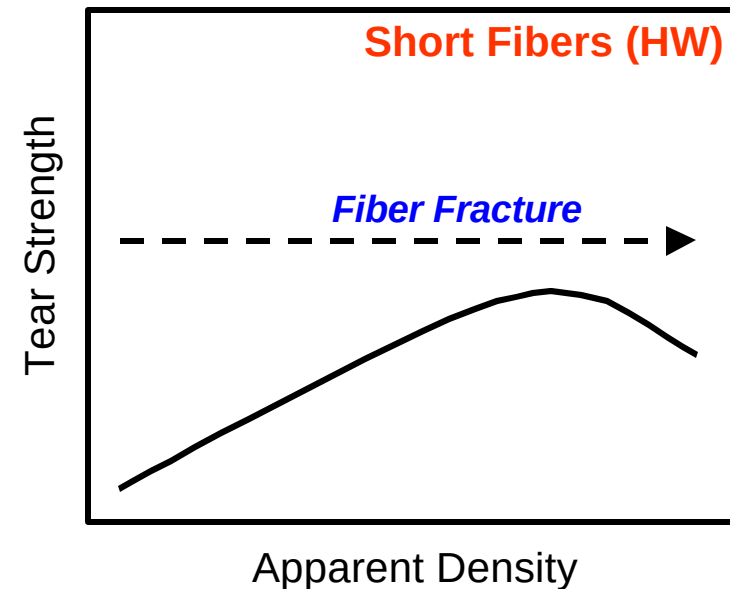
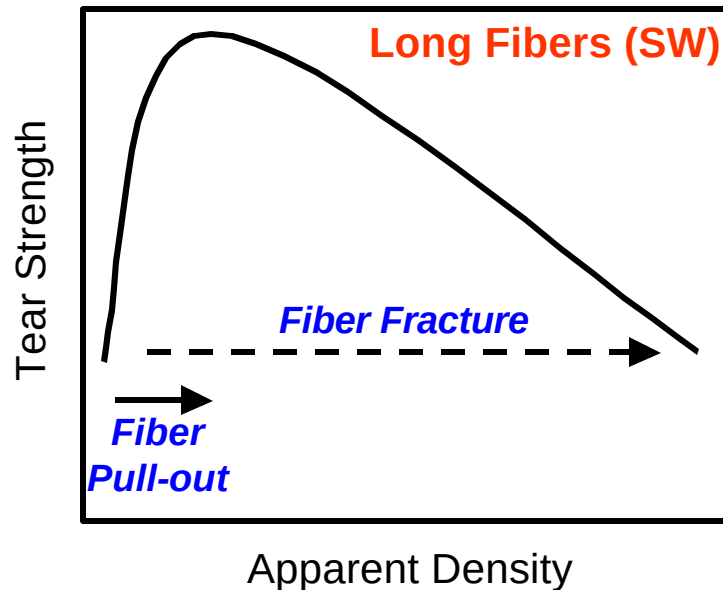
- (1) **Plastic elongation of fibers**
- (2) **Breaking of bonds** (Inter-fiber bonds)
- (3) **Breaking of fibers** (Fiber pull-out)
- (4) **Fiber-to-fiber friction**

From these the two most important types of energy dissipation are:

- **Fiber fracture** – This is when the fiber itself is broken during the tear test.
- **Fiber pull-out** – This is when fibers are pulled out of the sheet along the edge of the tear. In order to accomplish this, **inter-fiber bonds** must be **broken**.

We can think of the tear strength as the result of the competition between these two factors

Tear strength vs. apparent sheet density (softwood case)



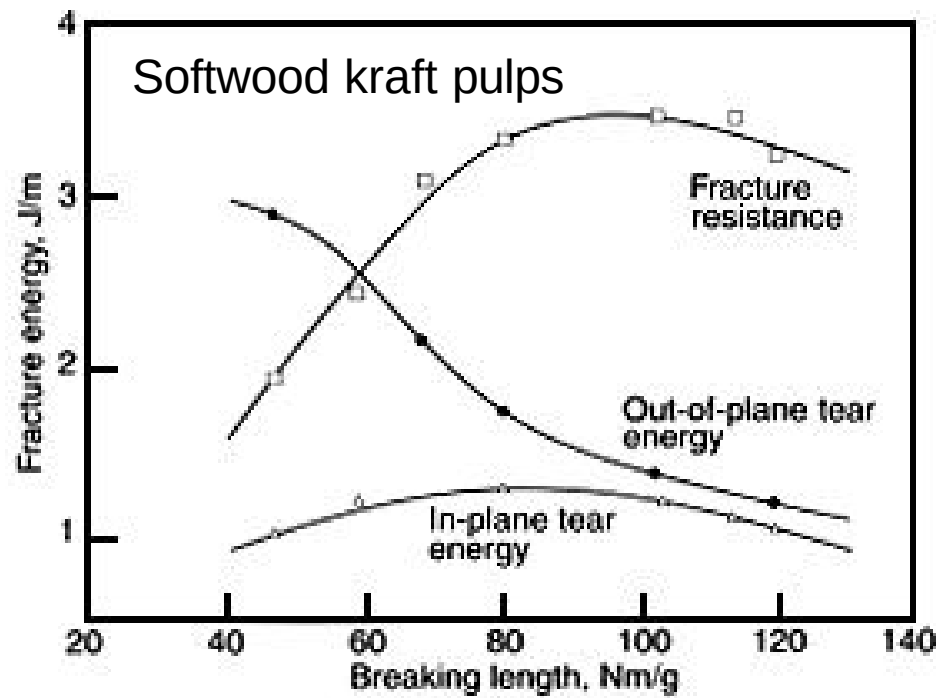
Initially tear strength is low, as there are few fiber-to-fiber bonds making the pull out resistance low, and also the fiber fracture low.

The tear strength rapidly increases as fiber pull out becomes more difficult and more fiber are being fractured.

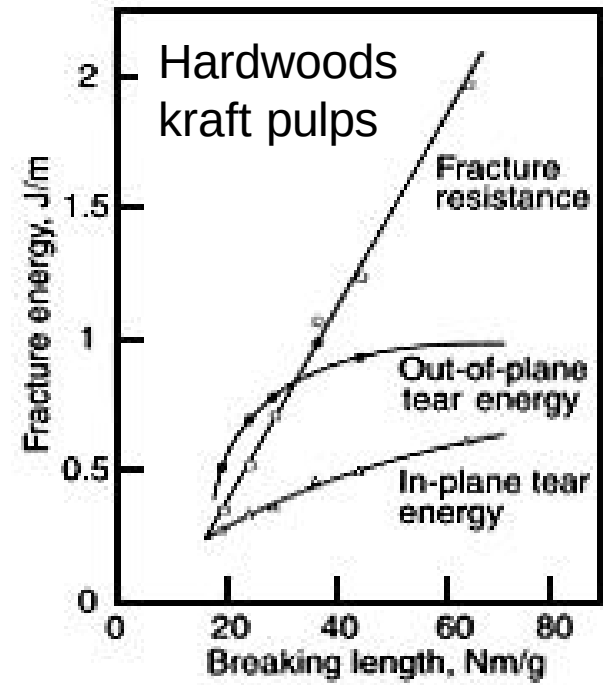
A maximum is reached and then the tear strength begins to decrease. This decrease can be attributed to a decrease in the fiber pull out and an increase in fiber fracture. Eventually, very little fiber pull out takes place and only fiber fracture occurs. Fiber fracture is a brittle type fracture and in general takes less energy than pulling out fibers.

Tear strength vs. apparent sheet density (hardwood case)

- For short fibers the situation is different.
- The short length of the fibers makes it difficult to have fibers with a long pull out (i.e. dissipating a lot of energy).
- Therefore, as bonding increases, fiber fracture increases while fiber pull out remains relatively constant.
- The result is a rise in tear strength over a much greater region for hardwood fibers.



refining →



refining →

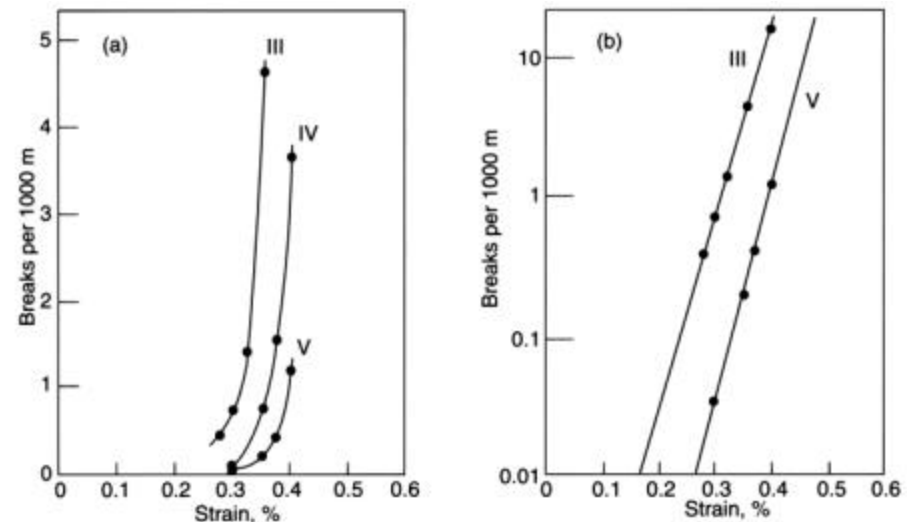
Fracture Toughness and Tear Resistance

- **Failure of a running web** is usually due to a **defect** in the **paper** or a **transient peak** in web tension that causes failure at an otherwise harmless defect.
- **Fracture toughness** measures the ability of paper to **resist the growth** of small incipient **cracks**.
- **Tear strength** has been traditionally used for this purpose, but it is not related to web runnability, experimentally or theoretically.

- Fracture toughness, or fracture resistance, is a material property that describes the ability of paper to resist a flaw from becoming a large crack.
- If an existing crack grows, elastic energy releases because stress vanishes at the crack faces.
- The Griffith criterion says that crack cannot grow unless this released energy is at least equal to the energy necessary to overcome the fracture resistance or toughness of the material.

Web Breaks and Fracture Toughness

- Web **breaks** are **relatively infrequent**.
- If runnability is measured as the mean distance between web breaks, then a typical value is **10^6 m or more between breaks**
- A paper web fails if the **local strength is too low** or momentary **load is too high**.
- The **frequency** of breaks increases with **increasing web tension**, sometimes even exponentially.



Break frequency of newsprint webs in linear and logarithmic scale vs. tension on a winding device run at 400 m/min with curves corresponding to different papers

- Significant levels of breaks occur at web tensions that are an order of magnitude lower than the tensile strength of paper.
- Breaks are due to distinct flaws or defects in the paper web.
- In papers made from mechanical furnish, shives can cause breaks.
- Good pulp screening has greatly improved runnability.
- Low moisture content makes paper brittle.
- Local strength minima causing breaks in the web depend on the nature and size of defects.

Furnish Effects

- The main use of **fracture toughness** is evaluation of the **efficiency of reinforcement pulps** in improving the **runnability** of printing papers made from **mechanical pulps**.
- **Reinforcement effect**, when **softwood kraft pulp** was added to **pressure ground wood (PGW)**.
- The **fracture toughness** and the out of plane tear energy increase when replacing mechanical pulp with kraft.

