What is Yield Stress and Why does it Matter?

By Neil Cunningham
Founder, Rheology School

What is Yield Stress?

Some materials can better be described as soft solids than as fluids. Strong gels and thick pastes possess an inherent structure to such a degree that they will not flow appreciably unless left for a very long time. Many less obvious robust materials also possess such a structure, albeit more delicate. One property of soft solids that will give us a more representation characterization is yield stress.

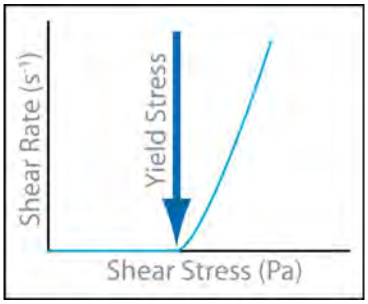

Figure 1

For example, open a new jar of mayonnaise and, without shaking or stirring; lay it on its side. If it hasn't been disturbed recently it shouldn't move noticeably over a period of a few minutes. It is safe to say that it has a very high viscosity-but we can also say that under the gentle conditions here the mayonnaise is, in fact, exhibiting behavior more akin to a soft-solid than a thick liquid. Turn the jar upright again and carefully insert a large cooking spatula into it. If we push the spatula laterally with a gentle force the mayonnaise will deform but will then return to its original vertical position when the force is removed-a dead giveaway of elastic (i.e. solid-like) behavior. We know that mayonnaise is not a true solid-it will flow, given long enough-but in some situations it suits us to assume that it is solid. Instead of measuring a liquid property, such as viscosity, we can then measure properties of solids so that we can measure properties such as yield stress.

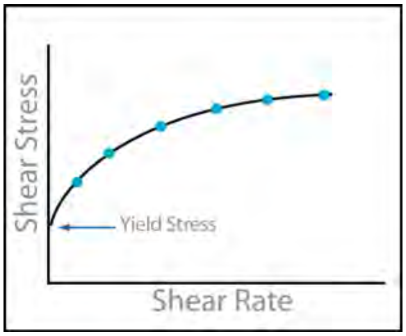

Figure 2

The imposition of an external stress of sufficient magnitude on these materials causes their structure to yield and flow results (figure 1). The yield stress is the applied stress we must exceed in order to make a structured fluid flow and it is a significant factor in many industrial processes such as pumping, spreading and coating. If the lateral force on the spatula, discussed above, exceeds a certain magnitude the mayonnaise won't relax back to its original position-we have caused it to yield resulting in a permanent (plastic or viscous) deformation-in other words, the mayonnaise has flowed.

The presence of a significant yield stress will impart various qualities to a fluid that may or may not be desirable. A yield stress will often inhibit flow under the relatively low stresses induced by gravity; giving sag and slump resistance to products such as adhesives, plaster, thick-film inks, molten chocolate, paint and fire-retardant coatings. With some products the presence of a yield stress is not so desirable, leading to, for example, dosing problems in gravity-feed systems or an excess of residue on the sides of inverted bottles. Many products are modified to produce a yield value for the purposes of particle suspension and to keep them from flowing at very low shear stress.

Measuring Yield Stress

Approximate yield stress measurements can be gained by plotting the shear stress values for a range of shear rates, fitting a curve to the data, and extrapolating through the stress axis. The intersect on the stress axis gives us our yield stress (figure 2). It is useful here to use a rheological math model, several of which are available on viscometer software packages-such as Brookfield's Rheocalc and Wingather Software-to quantify the intersect. In the sample shown, the Casson model would be employed.

A more exact method for obtaining yield stresses is to use a static vane-based test method. The vane is lowered into the undisturbed sample and then torqued slowly. The sample deforms elastically as the imposed stress increases until a yield stress is attained. At this point the sample starts to flow significantly and the measured stress falls from a peak (figure 3).

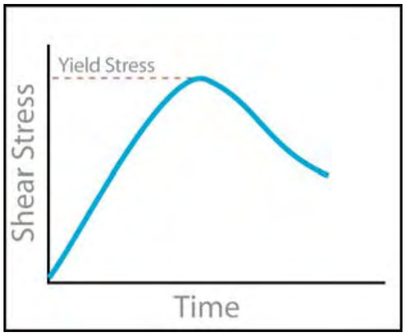

Figure 3

Table 1 shows typical yield stresses for a range of common products.

Table 1

Ketchup	**15 Pa**
Salad Dressing	**30 Pa**
Lithographic Ink	**40 Pa**
Mayonnaise	**100 Pa**
Skin Cream	**110 Pa**
Hair Gel	**135 Pa**

The Brookfield YR-1 and DV-III Ultra both have the capability to make this type of measurement, as well as, controlled stress rheometers such as the Brookfield R/S and R/S-CPS, which allow you to easily measure yield stress by incrementally increasing the shear stress applied to a material and recording the point at which significant shear commences.

This yield measurement is more representative of the way a soft solid is used, since the test material starts from a static, structured condition which is normally what happens in the real world.

Controlled Stress Testing

The ability to control the shear stress applied to a material, rather than just the shear rate, gives us a powerful tool for characterizing materials that, at least while at rest, behave more like solids than liquids. It is easy to use a controlled stress method to compare the ease with which materials can be pumped in a manufacturing process. For example, of the two sealants shown in figure 4, sample B can prove difficult to extrude from a cartridge unless the temperature is raised.

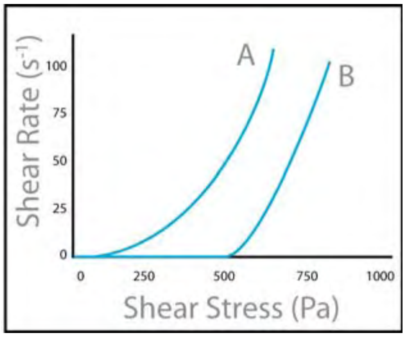

Figure 4

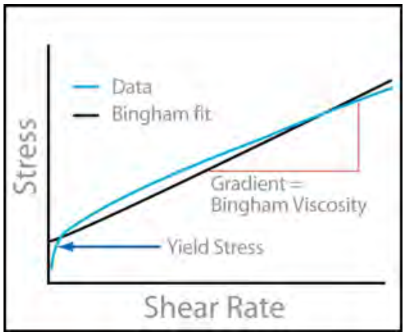

Figure 5

While it is easy to visually compare these two samples it is more desirable to quantify their characteristic yield stresses. This is done by fitting a simple rheological model, the Bingham model (see figure 5, plotted here with shear rate on the x-axis), to the data. Using the Bingham model entails fitting a straight line through the shear stress/shear rate data-points and extrapolating the line through the stress axis. For materials that exhibit distinct yield behavior, the intercept of the line through the stress axis represents a yield stress.

Comparing the yield stresses for our two sealants we have 170 Pa for sample 1 and 510 Pa for sample 2. It is now a simple matter to set a maximum permissible yield stress for quality control purposes.

The use of simple rheological models such as the Bingham model is an excellent way of accessing important rheological information for quick and easy QC tests. The Bingham model is one of several that are features on the Rheo3000 software, all of which can be utilized by non-technical staff with just a couple mouse clicks.

The techniques discussed here are currently in widespread use in industries as diverse as cosmetics, food, pharmaceuticals, coatings and adhesives. With the arrival of robust, versatile and easy-to-use rheometers such as the R/S range, powerful methods that were once exclusive to cash (and time) rich research departments are now available to today's results-oriented, commercial laboratories.

Yield Stress Instruments

The YR-1 from Brookfield Engineering is an excellent tool for measuring yield stress. It is a simple-to-use low-cost alternative to complicated, full-featured laboratory rheometers. The YR-1 is designed to be used right on the production floor by technicians. Simply select a test, lower the vane spindle into the product, press GO, and the instrument displays the result in a single shear stress number for your material's yield value. It couldn't be easier. Go to www.brookfieldengineering.com to learn more about the YR-1 features and benefits.

The DV-III Ultra, also from Brookfield Engineering, combines the sophisticated features of a viscosity testing instrument with a yield stress measurement capability. With the ability to measure viscosity and characterize flow behavior on its impressive list of features and benefitsthe DV-III Ultra is one of the best values in the rheometer marketplace today. Go to www.brookfieldengineering.com to see the advantages the DV-III Ultra has to offer..

- Built-in Math Models: Models provide data analysis without the use of external software. Casson Yield Values, NCA/CMA Casson (Chocolate), Power Law, Bingham Plastic and IPC Paste Analysis calculations are included
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About Neil Cunningham

Neil Cunningham entered the field of rheology through sales and application development roles at rheometer manufacturers TA instruments, Rheometric Scientific and Brookfield Engineering. Since that time he has trained over a thousand instrument users across several hundred companies and has worked with a huge range of manufactured liquids and semi-solids. Neil is highly experienced in the practical issues facing researchers and quality controllers and possesses an excellent working knowledge of most rheometers and viscometer systems in use today. He is the founder of the Rheology School, which provides rheology testing, viscosity testing, texture analysis, practical training courses and advice to manufacturers of pharmaceuticals, cosmetics, food, coatings and a host of other industries worldwide.

For more information on yield stress, rheology, or the products mentioned please visit:
BrookfieldEngineering.com, ViscosityJournal.com, TextureAnalysis.com, and RheologySchool.com

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