# The Product Fits the Bill – Successful Product Design

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***Getting it Right the First Time.*** Engineers are responsible for the design of new products. A lot of work goes into getting the chemistry just right as the product is designed to achieve a prescribed behavior. In the consumer product industry, it must clean clothes as well as make the laundry smell fresh by adding heat or time activated chemicals that cling to clean clothes. In the pharmaceutical industry, it must aid in the cure of disease or ailment. In the cosmetic industry, it means the addition of particles that induce skin tightening or lubrication. These product qualities are key product attributes which must be present to achieve successful product development. Much energy is invested in the design to attain these qualities. However, the segregating and/or free flow nature of the product is given little or no thought; process engineers are left to make obsolete handling processes work with newly designed materials. This is not an optimal situation and generally results in significant delay in getting the product to market – thereby loosing considerable potential revenue. This situation can be avoided by using sound product design principles to create or maintain desired flowability prior to the final product design. Many techniques and principles are common to both product design and successful process design. In process design, is it understood that the process geometry must be based on key flow properties that describe behavior in the system. With proper data regarding these key properties, models can be used to predict process behavior. Design is carried out, assuming conservative estimates of flow properties and process behavior. A similar design methodology can be utilized for product design. The properties data required are particle scale properties such as particle size distribution, moisture content, particle shape, surface hydrophobisity, and chemical or crystallization bonding between particles. Models exist that relate particle scale properties to flow property behavior. These are generally developed for mono-disperse particle systems. However, knowledge of particle interactions can be used to extend these simple predictive models to more complex systems. There is insufficient space in this article to develop the complete set of product design rules, so we will highlight two and present a general approach for use when faced with product design issues.

***Two Primary Product Design Rules:***

- Understand the role of particle scale properties on bulk unconfined yield strength.
- Calculate strength directly from models involving particle scale properties and by some direct measurements of bulk properties.

First, designers must recognize that understanding the role of particle scale properties on bulk unconfined yield strength is a key relationship. All other important properties are affected by the degree of cohesive strength in the bulk. So, this article will focus on bulk strength. Second, the current state of modeling does not allow direct calculation of strength from particle scale properties alone. The particle system is too complex to allow this. Thus, the engineer must rely on some direct measurement of key properties and extrapolate system behavior from there. The key is minimizing the test(s) required. The goal is to measure key properties of pure components in a mixture and combine these properties in such a way as to predict the properties of any mixture containing the same components. Unfortunately, simple mixing rules quite often do not apply.

***First Example.*** As an example, consider a two-ingredient mixture. A simple linear mixing rule suggests that the strength of the mixture would be a linear combination of the pure components. Likewise, it can be assumed that the permeability of this mixture would be a linear combination of the pure component permeability values. However, with real mixtures, such is not the case. The highest strength occurs at some mixture of pure coarse and pure fine. Likewise, the lowest permeability occurs with some mixture between these two extremes (Figure 1).

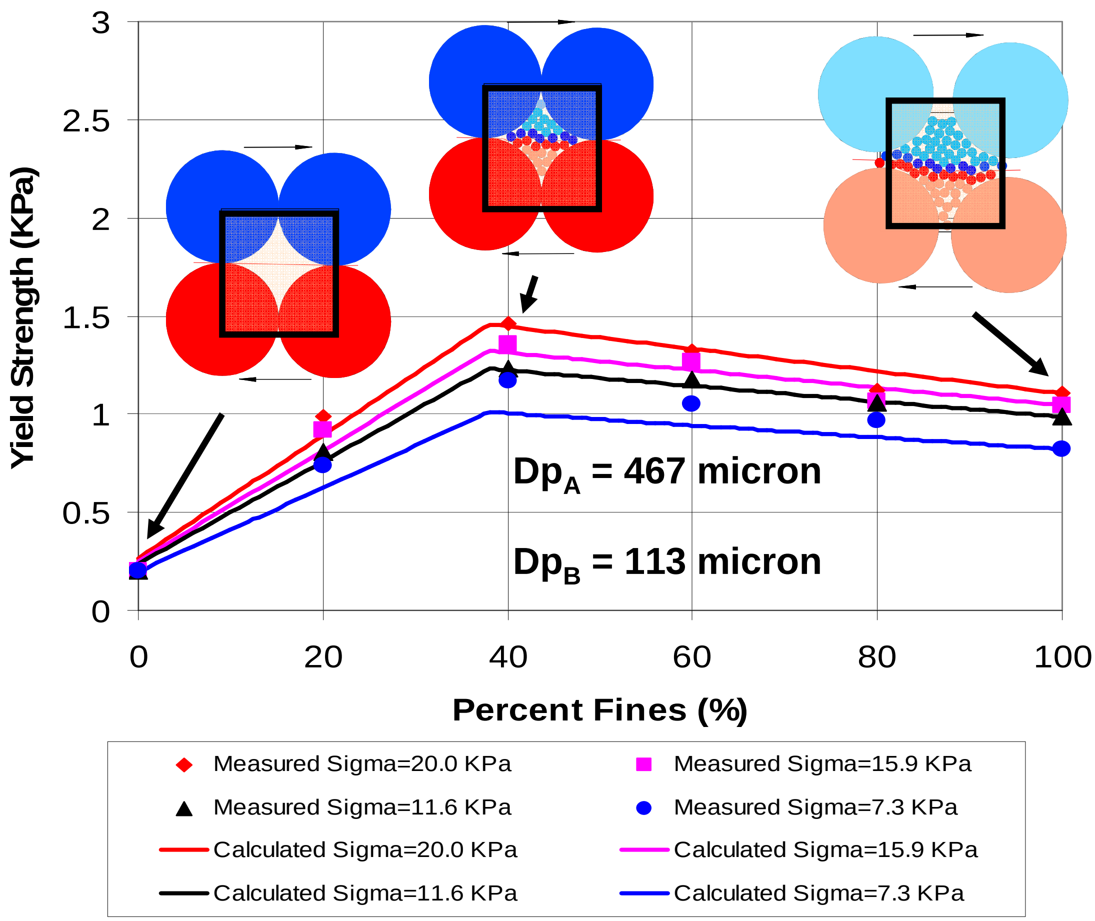


*Figure 1. Effect of Fines on Bulk Yield strength*

At Material Flow Solutions, we have developed mixing rules that allow us to combine the strength values of two or more components to predict the mixture strength. Figure 1 shows the measured strength for a bimodal material, indicating maximum strength at the point where all the solids voids were filled with fines. The lines are the predicted values based on our non-linear mixing rules. Similar results occur with tri-modal and poly-disperse systems. It is important to note that the prediction is made measuring only the strength of the pure components. The model takes care of rest – greatly reducing the number of tests required for traditional product design. Consider the simple bimodal mixture. Because of the non-linear behavior of the mixture, one would need to measure the flow properties of six to eight samples to accurately predict the trend in properties. Using the mixing model and just two flow property measurements, we achieve the same result. If this were a ploy-disperse system, then significantly more measurements would need to be made to characterize the flow property behavior. However, the same information could be obtained with just a few flow properties tests and the poly-disperse flow model. In very complex systems where both the moisture content and particle size vary, we can often measure flow properties at four to five conditions and be able to predict flow property behavior at literally hundreds of product compositions, moisture contents, and particle sizes using our scale mixing rules.

***Second Example.*** Frequently, engineers find prediction of strength from first principle difficult due to one (or both) of two issues. First, surface geometry greatly affects strength. Second, particle shape greatly affects strength. However, in many cases it is possible to incorpor-ate the shape effect into the prediction of strength. The main principle driving the effects of particle shape is that strength is directly proportional to the number of contacts-per-particle for non-spherical particles. Estimating the number of these contacts using optical techniques or other means allows estimation of the effect of shape on bulk yield strength. Figure 2 shows the effect of particle shape on cohesive flow properties. The initial case strength in this figure was based on the strength between nearly spherical particles. However, counting the contacts per particle, and taking account of the direction of those contacts, allows correction of the round strength data to be able to predict strength of irregular shaped particles (dashed line). In other words, we measure the strength of just the round particles and use the shape models to predict the strength of a bulk material made of any shape and size particle.

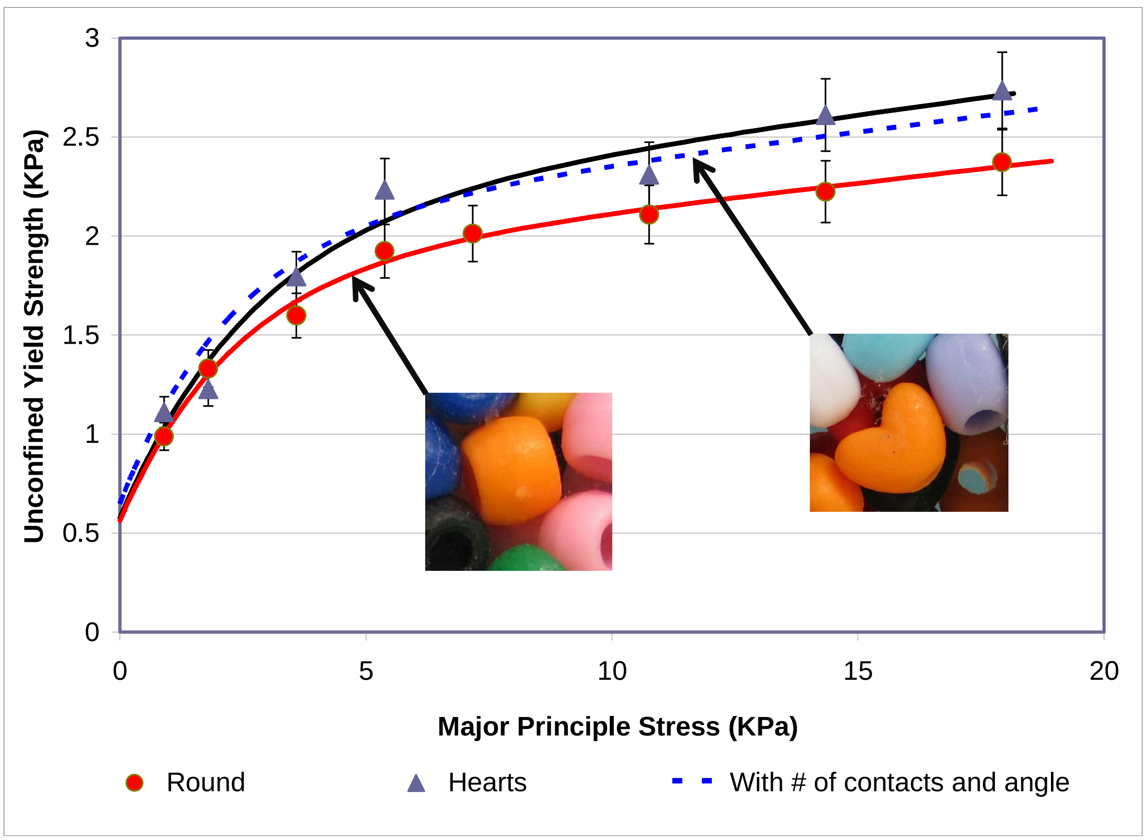


*Figure 2. Effect of shape on strength of bulk materials*

***The Bottom Line.*** The examples in this article are simplified to show the technique. However, we have applied these scale laws to real mixtures such as clays, detergents, pharmaceuticals, food mixtures, plastics, and granular and powder fuels with very good success. We can also predict and measure segregation tendencies with a variety of bulk mixtures. Engineers who understand and utilize this methodology shorten the time to market as they are able to control processes based on accurate scale up equations, thereby increasing company revenue. Let us help you design your next product to enhance flowability, or let us provide you with custom design constraints specific to your material to prevent bad acting product.

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