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Green-Packing Density and the Effects of Particle Size on Clay Performance

The range of clay particle sizes present in any clay or claybody is critically important and affects five primary performance characteristics: 1) plasticity/adhesion, 2) working structure, 3) drying shrinkage, 4) body strength at bone-dry and bisque-fired states, and 5) firing shrinkage.

1. ***Plasticity and Adhesion*** - The plastic and adhesive qualities of clay depend on the fineness of the clay particles - the finer the particle, the more water layers present, and thus more lubrication and greater plastic and adhesive qualities. Exactly the opposite occurs with larger particle sizes - less water layers, less plasticity and adhesion.
2. ***Working Structure*** - The ability of clay to hold its form while wet depends on contact points between particles and interference to movement provided by larger particles. The water hull lubricates the surfaces but doesn't prevent particles from physically touching each other, and the friction of those contact points creates working structure. Less water content gives more friction, producing stiffer clay. More water content reduces friction, and enough water eliminates friction, producing a slurry or slip. With appropriate water content, very small clay particles give many contact points, high plasticity, and good working structure, but if the average particle size is too small, the high number of water layers gives problematic drying shrinkage. If the clay particles are uniformly large in a claybody, drying shrinkage is reduced, but plasticity is also reduced and the number of contact points decreases, giving poor working structure.
3. ***Drying Shrinkage*** - The loss of water layers by evaporation causes drying shrinkage, and the finer the average particle size, the more the water layers, and thus the higher the drying shrinkage. High shrinkage during drying causes cracking and warping. The larger the average particle size, the less water layers, and thus less drying shrinkage.
4. ***Dry/Bisque Strength*** – Fine particle size mean more adhesion contact points between particles as the clay dries, giving greater strength in dry greenware and in bisqueware. Inversely, larger average particle size gives less contact points between particles and thus lower strength at bone dry and bisque-fired stages.
5. ***Firing Shrinkage*** – When any clay is fired above lowfire temperatures, glass begins forming within the platelets and seeps into the intervening spaces or voids. As this happens the platelets shrink, causing firing shrinkage. The larger the average particle size, the more space between to fill with glass, and thus the greater the firing shrinkage, which if excessive can cause cracking and warpage.

To Sum This Up, the advantages of clay with very small platelet size are high plasticity and adhesive qualities, fair working structure due to friction from many contact points, high dry/bisque strength due to many contact points, and low firing shrinkage due to few large voids. The disadvantages are drying shrinkage so high as to make the clay unusable, and no larger particles to increase working structure. The only advantage of clay with larger average platelet sizes is low drying shrinkage, while the many disadvantages include low plasticity due to few water layers, poor working structure due to few contact points, low dry/bisque strength due to few contact points, and high firing shrinkage due to large voids between particles.

Green-Packing Density and the Room Full of Basketballs

Given this information, you might think that the ideal solution would be an intermediate particle size, but that's not the case, since both small and large particles provide desirable qualities. The ideal compromise in all cases is a claybody with a broad *distribution of particle sizes*, and that brings up the *room full of basketballs* analogy. If you fill a room with hundreds of basketballs, each basketball will have up to six contact points with its neighbors. In terms of basketballs, the room is full, but there is space for thousands of tennis balls, each filling a void between basketballs. The addition of tennis balls means far less open space and far more contact points, but is the room full? No, because there's room for hundreds of thousands of marbles filling the spaces between basketballs and tennis balls, once again decreasing the voids and multiplying the contact points. And then there's room for millions of B-Bs filling the voids between basketballs, tennis balls, and marbles, eliminating most of the remaining open space and almost infinitely multiplying contact points. You could go further with steel shot and grains of sand, in each case decreasing void space and greatly multiplying contact points.

Envision the same in a claybody, where the open spaces are water in the moist state and air when dry. With a broad distribution of particle sizes, the particles nest together to give maximum contact points, a reasonable number of water layers, and minimal open spaces between particles. This is known as *green packing den*sity, or *GPD*.

In a clay body with a wide range of particle sizes and thus good GPD, the smaller clay particles give good plasticity and increase the number of contact points, giving good adhesion, increased friction, good working structure, and good dry/bisque strength. They fill most of the volume of voids between medium-size and larger particles, decreasing firing shrinkage. The medium and larger clay particles further improve working structure by physically restricting movement of smaller particles, and they reduce the number of water layers, decreasing drying shrinkage.

Non-plastics (non-clay materials) are added to claybodies for a variety of reasons that will be discussed, but in appropriate amounts they always improve working structure, because they do not develop a water hull and therefore increase friction between particles, and because the particles are huge in comparison to clay platelets they act as reinforcing elements impeding movement.