FILLERS IN PVC
A REVIEW OF THE BASICS

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Introduction

Fillers come in many types, shapes, and sizes. The PVC formulator needs to select a filler that will process well while providing the required physical performance at the lowest possible formulation cost. A good understanding of the role of fillers can lead to significant savings in material costs and expand a compound's performance envelope, allowing it to compete in new areas and against other resins.

This document covers some of the basic considerations that enter into the filler selection process. We will review the properties of fillers and see how they affect the performance of the PVC compounds they are used in. We will also learn how to lower a formulation's cost by using fillers, both as extenders and as performance additives.

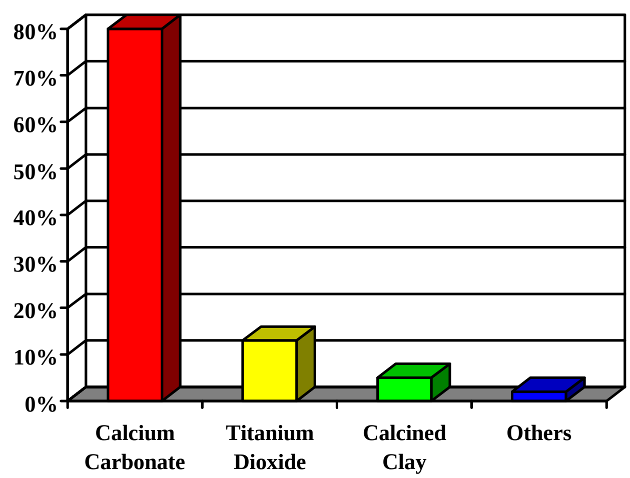
The Role of Fillers

Fillers are used for a wide variety of reasons. They can extend resin, increase stiffness and strength, improve impact performance, and shorten cycle times. They prevent hang-up in dies and neutralize the products of degradation. Fillers can also be used to add color, opacity, and conductivity to a compound. Unique property combinations can be achieved through the use of fillers.

Traditionally a filler was a low cost material of relatively large particle size that lowered a formulation's cost simply because it was less expensive than the other ingredients in the formulation. Today a "filler" can be a true performance additive. Advances in compounding technology allow the use of much finer fillers that could not be used in the past. Today's filler products are tailored for specific applications and designed to deliver value in new and interesting ways.

Filler Types

Approximately 80% of all the filler used in PVC is calcium carbonate. Titanium dioxide is second at around 12%, followed by calcined clay at about 5%. The remaining few percent is taken up by other materials, including glass and talc.



Calcium carbonate products are available in a wide range of sizes. They are produced by grinding limestone and by precipitation. Titanium dioxide is used as a white pigment and UV stabilizer. Calcined clay goes into wire and cable formulations where it improves electrical properties. The remaining fillers find their role in a variety of specialty applications.

Primary Filler Properties

Particle Size - Most fillers are grouped and ranked by their particle size. There are a number of different ways to measure and report particle size. When comparing two fillers one must make sure that the comparisons are made using comparable measurement techniques. Even small differences can be significant, especially where fine fillers are involved.

The term "particle size" is in itself misleading. Even a small sample of a filler will contain many particles of different sizes. What we are actually dealing with is a particle size distribution. Most data sheets give the average size or the midpoint (median) value in their product's size distribution.

"Top size" is another term used to describe a filler's particle size. It is a carry-over from screened stone where the "top size" of the product was the finest screen that all the material would pass through (the one on the *top* of the stack of screens). Its definition becomes less clear when dealing fine fillers. Classifiers do not produce perfect top cuts and fine fillers tend to stick together causing agglomerates that act like coarser particles. It is technically more appropriate to speak of a "95% finer than" or "99% finer than" size.

Finally there is "grit", which is a very small quantity of grossly oversize particles. Grit is an important factor in applications sensitive to surface blemishes or compounds that are processed through screen packs. The trouble with grit is that often the quantities involved are so small that they can not be measured by normal sampling procedures.

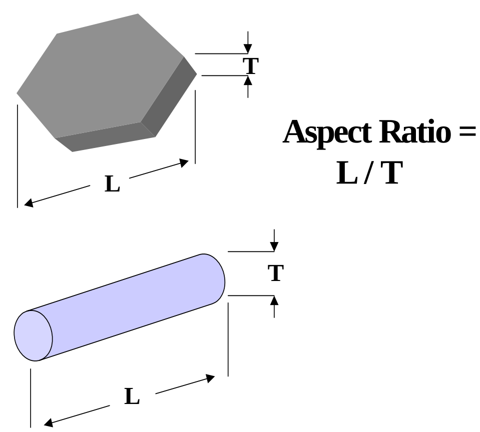
Particle Shape - Filler particles come in a variety of shapes, as well as sizes. There are spheres, rods, platelets, and irregular shapes of varying proportions. The only characteristic of shape I would like to define here is aspect ratio. The aspect ratio of a filler particle is the ratio between the particle's largest dimension and its smallest. In the case of a rod it would be the length divided by the diameter. A sphere would have an aspect ratio of 1:1 while a fiber can be 20:1. Shape plays an important role in defining a filler's reinforcing characteristics, as we shall see later.

Some Additional Properties

Hardness – Abrasion is a function of hardness and particle size. This relationship with particle size is not linear. Coarser particles are much more abrasive to plastics processing equipment than finer ones. The contribution of impurities must also be considered.

Color – A filler can contribute to the color of a compound. If color is important the pigment package must be adjusted to compensate for the affect of the filler. The dry color of the filler can be misleading. A bright white filler may produce a gray color in the polymer. The only way to know how a filler will affect color is to test it in the compounded formulation.

Aspect Ratio



Specific Gravity – The specific gravity of the filler must be taken into account when calculating the cost of a compound because the parts produced are sold on a volume, not a weight, basis. Most mineral fillers have a relatively high specific gravity and will therefore raise the specific gravity of the compounds they are used in. As a result it will take more pounds of compound to make the finished part.

This change in specific gravity must also be taken into account when determining the weight of a Brabender batch because to compare Brabender curves they must all be run with the same volume, not weight, of material in the bowl.

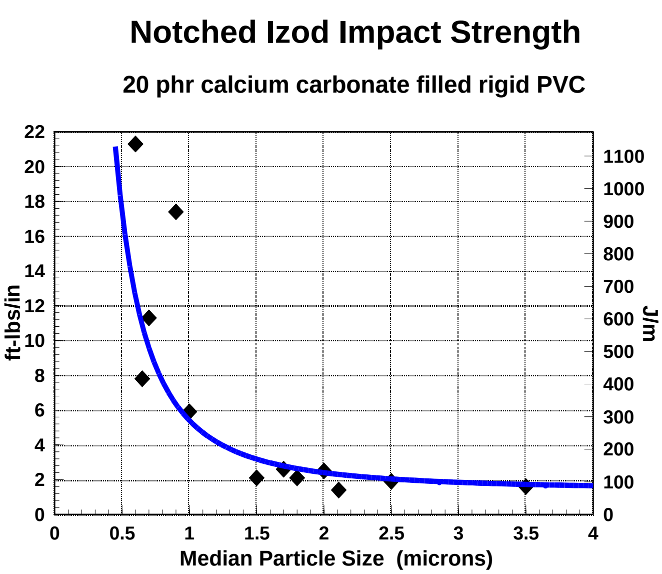
Surface Treatment – Most of the fillers sold to PVC applications are surface treated. This treatment is usually a fatty acid, such as stearic acid. A coating can improve the dispersion of the filler particles during melt compounding, reduce the adsorbtion of other formulation ingredients onto the filler's surface, improve the filler's dry flow properties, and change its processing characteristics.

Surface treatment of the filler also affects the physical properties of the product being produced. Functional coatings are used on various fillers in other resin systems. However, fatty acid coated calcium carbonate is still the dominant filler, by far, in the PVC industry.

Powder Flow Properties – The dry flow properties of a filler, and their affect on the flowability of the PVC compound, are also important. Today's PVC plants contain large investments in automated material handling equipment. The filler must make it through the system of hoppers and conveying lines without creating a problem. Some preliminary indications can be obtained with laboratory flow tests but they are of limited value. In the end it is very much a "try it and see what happens" situation.

From the Properties of the Filler to the Properties of the Compound

Particle Size and Impact Strength – The size of the filler used can have a dramatic affect on the impact strength of a PVC compound. The graph below shows the relationship between impact strength and filler particle size for calcium carbonate in rigid PVC. The relationship is not linear. Where the carbonate size is larger than one micron the impact strength is relatively low but as the carbonate size is reduced into the sub micron range the impact strength of the compound increases dramatically.



We can see how, because of this, it is meaningless to talk about a filler's performance without specifying the size of the filler used. The same type of filler can produce vastly different impact test results depending on its particle size.

Stiffness and Aspect Ratio –Since most fillers are much stiffer than the polymer they are used in they increase stiffness. The stiffness (flexural modulus) of the composite increases as a linear function of the filler's loading level and aspect ratio. The aspect ratio here is the ratio after compounding. A filler's aspect ratio can be reduced by particle breakage during melt compounding.

Impact/Stiffness Balance – Theoretically, because impact strength is a function of particle size and stiffness is a function of aspect ratio, one can get the best of both worlds with a high aspect ratio filler of very small particle size. Unfortunately, it is very difficult to produce a filler with both these properties. This is because the critical size is the largest dimension of the filler particle. It would become very fragile because to also have a high aspect ratio it would have to be extremely thin. Still, some interesting property balances can be achieved by using the finest platy fillers available with increased levels of impact modifier.

Tensile Properties – The affect that a filler will have on tensile strength depends on how much force it takes to pull it out of the polymer matrix. (Assuming that its own tensile strength is considerably higher than that of the polymer matrix, which is the case for most fillers.) For a typical calcium carbonate filler tensile strength will decrease slightly as filler is added. This is because the surface coating that helps increase impact strength lowers the particle's adhesion to the polymer. Higher aspect ratio fillers that increase modulus will usually also increase tensile strength because there is more surface to grip the polymer.

Tensile elongation at break is usually an indication of toughness and increases as the particle size of the filler decreases.

Calcium Carbonate for Rigid PVC

The following scenarios demonstrate how calcium carbonate products can be used to lower the overall cost of a PVC formulation. They make use of the relationships we have discussed.

As an Extender for the Compound **-** This is the traditional use for ground limestone in rigid PVC. The goal is to add as much filler to a formulation as is possible. Since the filler costs less than the compound the more one adds the lower the formulation cost.

The amount that is added is determined by the physical requirements of the product. In this situation the fillers are usually 2 microns or larger and will have a negative effect on some critical property, such as impact strength.

This approach is valid as long as no impact modifier is used. If impact modifier is necessary one should first consider a finer calcium carbonate. It is always more cost effective to increase impact performance by reducing the filler's particle size than it is to increase it by adding impact modifier.

In Formulations with Impact Modifier – In these formulations impact modifier is added to the formulation to obtain the required impact performance. The filler size is usually finer, around 1 micron, because you don't want the filler and impact modifier to be working against each other.

When comparing fillers in this category one should first determine the lowest level of impact modifier needed for each formulation and then compare formulation costs. It is very likely that the lowest cost filler will not produce the least expensive compound because it may require more impact modifier.

As An Impact Modifier Extender **-** The addition of an ultrafine (average particle size less than 0.1 microns) calcium carbonate to a rigid PVC formulation can increase impact performance. To obtain this result the proper loading level must be determined by lab experiment or by a series of plant trials. It is usually in the 8-15phr range, depending on how much titanium dioxide is in the formulation.

This has proved to be a cost-effective approach in formulations containing 5 or more parts of impact modifier. To determine the proper loading levels an experiment is run testing different filler and impact modifier levels to see if there is a combination that provides the required performance at a lower formulation cost.

For Example: A formulation that contains a low loading of a 1 or 2 micron calcium carbonate and 8 parts of impact modifier may be able to do the job with only 6 parts of impact modifier if the filler is replaced with an ultrafine carbonate at the optimum level. The filler cost in the formulation increases but the impact modifier cost decreases by a much larger value resulting in a significant savings to the compounder.

Processing

Dispersion – The filler must be well dispersed in the resin or the physical properties of the compounded PVC will be poor. Dispersion is not the same as mixing. To achieve good dispersion enough shear has to be put into the compound, during the melt compounding process, to break up any agglomerates of filler that may be present. Today's compounding equipment is capable of handling finer fillers than the single screw machines of the past.

Fusion – Proper fusion is also necessary to obtain good physical properties. The addition of fillers can change the fusion characteristics of a compound. It is advisable to run a Brabender curve on any new experimental compound to see if its lubricant package needs to be adjusted to compensate for a change in filler type or loading level.

Dry Flow – Finer fillers are usually more difficult to handle than coarser ones. They may present problems in material handling equipment designed for coarser products. This aspect of processing should also be monitored during a trial. Most handling problems can be solved by slight modifications to the handling system.