Practical considerations for loading conductive fillers into shielding elastomers

Understanding conductive filler loading is important when designing EMI gaskets.

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INTRODUCTION

ELASTOMERS LOADED WITH ELECTRICALLY conductive powders are commonly used in gaskets for EMI shielding applications in electronic devices such as computers, telecommunications equipment and medical devices.[1] A challenge in designing EMI gasketing materials is to provide sufficient shielding effectiveness while meeting application-specific elastomer requirements such as hardness and tensile properties.

For example, elastomeric polymers loaded with metal or metal-coated particles are commonly used for EMI shielding gaskets. The polymer must be highly loaded with the conductive filler in order to achieve sufficient conductivity for EMI shielding. The conductivity (as measured by volume resistivity) of shielding materials is commonly used as an indication of EMI shielding effectiveness. As the conductive filler loading level is increased, and as the target shielding effectiveness or conductivity is approached, the loaded materials also begin to take on physical and mechanical properties that may interfere with the fabrication and/or implementation of the EMI shielding gasket.

When designing EMI shielding gasket materials, it is instructive to analyze the relationships between conductive-filler loading and the resultant electrical and mechanical properties of the composite.

Using the example of a silicone elastomer loaded with a nickel graphite powder, this article illustrates the relationship of conductive-filler loading to volume resistivity, hardness, and tensile properties. While the silicone elastomer/nickel graphite combination is perhaps most common in EMI shielding gaskets, the basic principles discussed in this article may be applied to other types of conductive powder/elastomer systems.

LOADING CONDUCTIVE FILLERS INTO ELASTOMERS

Composite elastomers that use metal or metal-clad fillers for electrical conductivity feature a connected network of conductive particles that are bound by the elastomer resin. Commercial conductive fillers come in a variety of choices—metal-clad and pure metal materials, varying selections of particle-size distributions, and a selection of shapes. Common filler materials include nickel-coated graphite, silver, and silver-coated glass. Nickel graphite is available in an average particle size ranging from 35 micron (75% Ni or greater) to 120 micron (60% Ni or greater). Particle shapes include spherical, flake, and short fiber. Elastomers are a type of polymer commonly used for EMI shielding gaskets because of their rubber-like properties that form effective mechanical seals on enclosures. The electrical and physical properties of conductive elastomers depend both on the type of conductive filler chosen and the amount that is subsequently loaded.

DC resistance, as measured by volume resistivity in Ω • cm, is considered to be a reasonable indicator of how conductive gaskets will perform in an EMI shielding application, particularly at low frequency.[2] In fact, volume resistivity is recognized and widely used as a relatively simple and convenient indicator of shielding quality for EMI gaskets. Commercial conductive elastomers for EMI shielding gaskets that use nickel graphite fillers typically come with a specification that volume resistivity is less than 0.1 Ω • cm.[1, 3]

When being loaded with conductive filler, an elastomer is practically non-conductive up to that point where a connected-particle network has been formed to create an effective electrical circuit. A rapid drop in volume resistivity characterizes the onset of conductivity as conductive filler loading increases. For mono-sized spherical-shaped particles, the threshold point of connectivity is attained at a volume loading of 30% on geometric models.[4] Non-spherical shaped particles achieve threshold connectivity at levels significantly lower than 30% volume loading because of the geometric packing characteristics that are a function of their particle size distribution, shape, and roughness—simply put, some shapes pack together more readily.

It is convenient to use the apparent density of a powder to characterize its packing characteristics. Apparent density, the actual volume occupied by a mass of powder, is the weight in grams of a unit volume (cubic centimeters) of loose powder.[5] The basic relationships are as follows. Apparent density decreases with decreasing particle size. It also decreases with particle roughness but it increases as particles approach a spherical shape. Figure 1 depicts the effect of particle shape on apparent density. Equal masses of randomly loosely packed particles occupy significantly different volumes as their shape changes. On an equal weight basis for particles of fixed density, oblong particles occupy more volume than the spherical particles and thus have a lower apparent density. The lower apparent density filler would make the elastomer conductive at a lower loading level as compared to the filler with higher apparent density. Apparent density is useful in comparing fillers that have the same composition, but different particle shape. This shape effect is advantageous in producing highly connected particle networks within conductive elastomers. Used as conductive fillers, flake-shaped particles have an advantage over spherical particles in that low volume resistivity is attained at lower volume loading levels.

The common measure for loading fillers into polymers is by weight percent or parts filler per-hundred-weight (phw) polymer. Although convenient, loading based on weight does not account for the volume occupied by the filler within the elastomer; and it is the relative volume percent, or fraction, that the filler occupies within the material that is important. Volume loading is a more useful measure when making comparisons in the performance

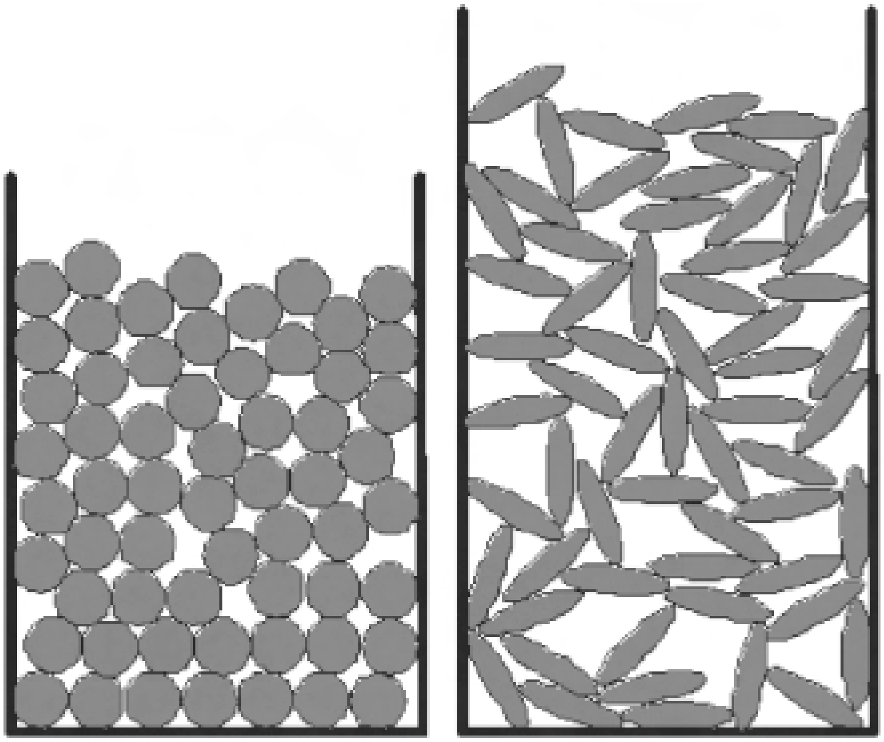

Figure 1. Depiction of two equal masses of loosely packed particles that have the same particle density and particle mass, but are different in shape. The spherical particles (left) pack more closely and occupy a smaller volume to produce a higher apparent density as compared to the oblong particles (right).

of different filler-elastomer systems. In evaluating conductive fillers, weight loading can be misleading because it does not account for differences in polymer density and conductive "true particle density." True particle density is the weight of a particle divided by the particle's volume, including closed pores. True particle density is used to determine volume loading in the elastomer and should not be confused with apparent density, which is used for a different purpose in characterizing the filler as described above.

Volume loading can be determined by determining the weight and density of the polymer and the filler particles thusly:

$$\text{Volume loading (\%)} = wf/[wp(df/dp) + wf] * 100 \quad (1)$$

Where wf, wp are the respective filler and polymer weights and df, dp are the respective true particle density and polymer density.

TEST PROCEDURES

The conductive filler used was nickel-coated graphite powder, with a weight composition of 65% nickel and 35% graphite. The particle size range was 0.003" to 0.0075" (75 to 190 microns) with an average particle size of 0.0047" (120 microns). The true particle density and apparent density of the nickel graphite powder was 268 lb/ft^3 (4.3 g/cm^3) and 86.8 lb/ft^3 (1.39 g/cm^3), respectively. Figure 2 shows micrographs of the flake-shaped particles. The silicone elastomer used in this work was a commercially available heat-cure methylvinylpolysiloxane resin base (a common type used in industry to produce EMI shielding gaskets). In absence of conductive filler, the Durometer Shore A hardness of the elastomer was 30 as-cured and 46 as-post-baked and had a density of 68.7 lb/ft^3 (1.1 g/cm^3). The conductive filler was compounded with silicone resin in a two-roll mill prior to curing in a hydraulic hot press to form 6" square sheets 0.067" (1.7 mm) thick. Following molding, each conductive rubber sheet was washed with isopropyl alcohol and then post-baked in an air-circulating oven. A total of eleven silicone elastomer sheets were prepared with various loading levels of nickel graphite filler ranging from 42.5 to 67.5 weight percent filler. Following post-baking, the conductive rubber sheets were cut to obtain 0.5" x 2.0" strips for volume resistivity measurement and "dog bone" strips for tensile tests. Volume resistivities of the cut strips were measured by the surface probe method adapted from military specification MIL-G-83528B using a Kiethely™ 580 four-point micro-ohmmeter. Hardness of the conductive rubber sheets was measured with a Shore A Durometer. Ultimate tensile strength (UTS) is the

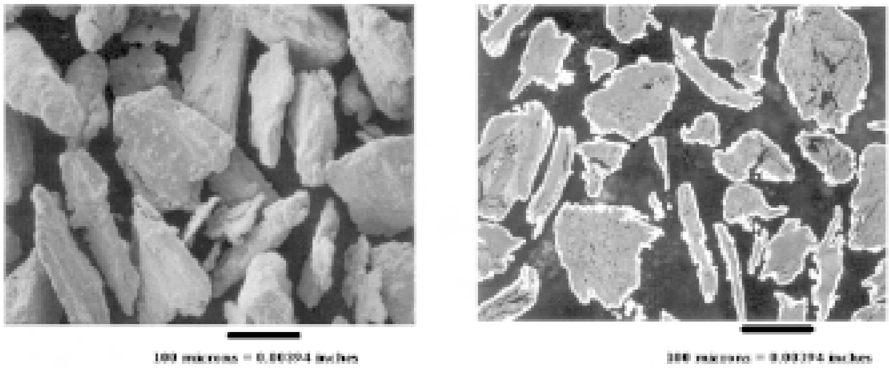

Figure 2. The nickel graphite particles used in the example are flake-shaped and have an average particle size of 0.0047" (120 microns). They are shown here in a scanning electron micrograph (left) and in cross-section in an optical micrograph (right). The cross section highlights the white nickel cladding contrasting the gray graphite core.

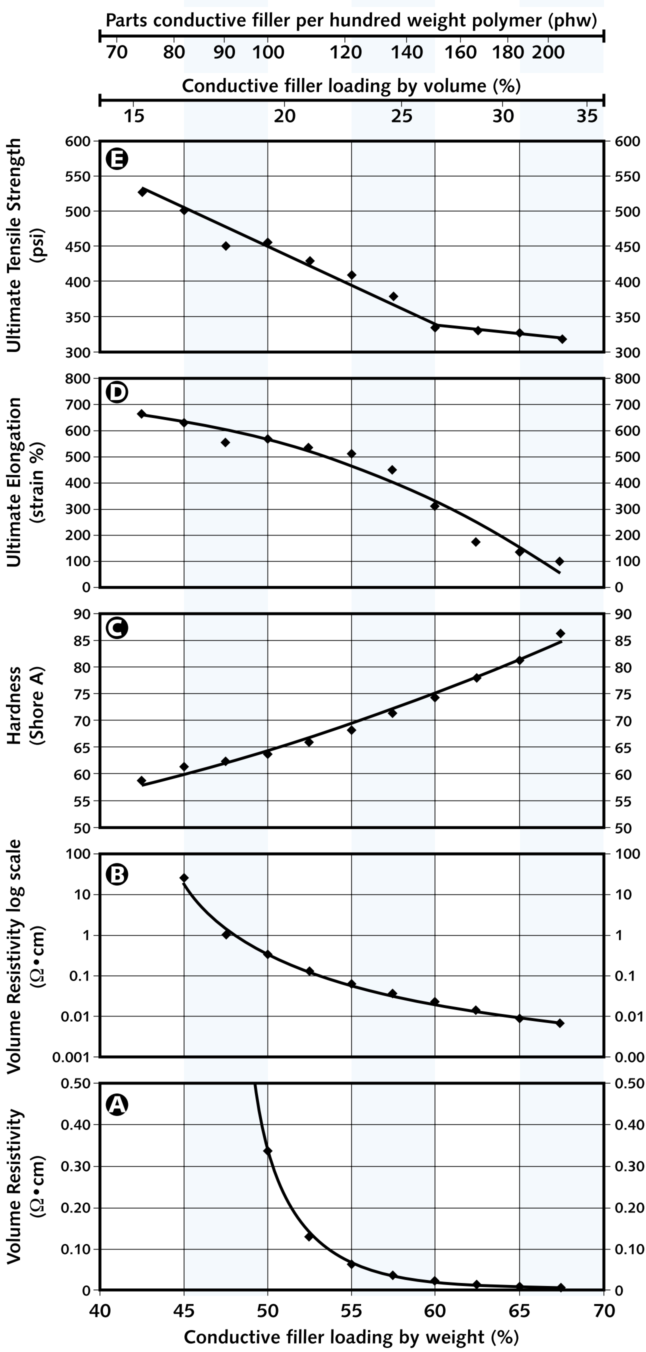

Figure 3. The relationships of volume resistivity (plots A & B), hardness (plot C), ultimate elongation (plot D), and UTS (plot E) are shown as functions of nickel graphite loading in a silicone elastomer.

maximum tensile stress—expressed in pounds per square inch (psi)—which, when applied to a "dog bone" sample strip causes it to rupture. Ultimate elongation is the amount of strain (expressed in percent of increase in length) of the "dog bone" sample at its point of rupture. The UTS and ultimate elongation values were derived from stress-strain curves obtained by an Instron™ tensile test instrument.

RESULTS

A compilation of volume resistivity, hardness, ultimate elongation, and UTS are shown as functions of conductive filler loading in Figure 3. Loading is expressed in units of weight percent, volume percent, and parts conductive filler per-hundred-weight (phw) polymer. Note that the relationships between the scales of weight loading and volume loading are not linear. Equation (1) can be used to convert between volume percent and weight percent loading. The unit of parts conductive filler per hundred weight polymer (phw) is calculated from percent weight as:

$$\text{phw} = [\text{weight }\%/(100-\text{weight}\%)] \times 100 \qquad (2)$$

The plots begin at a filler weight loading level of 42.5% (15.9% by volume). At this lowest loading level, the physical properties of the elastomer were measured; but the material was not conductive enough to measure volume resistivity. The end of the series is marked by the highest loading level of 67.5% by weight (34.7% by volume). That highest level was the limit/cutoff point at which conductive filler could no longer be added to the silicone resin, if the later were to remain "workable" enough to allow molding. Different filler and elastomer types will have their own characteristics for maximum loading.

ELECTRICAL PROPERTY: VOLUME RESISTIVITY

Plots A and B in Figure 3 show, on linear and logarithmic scales, a rapid decrease in volume resistivity with increasing filler loading. This rapid decrease is characteristic of the loading level at which the conductive particles begin to come into contact with one another to form a conductive network. In this particular case, the rapid decrease began at a loading level somewhere between 42.5 and 45.0% weight loading. The volume resistivity continued to decrease to a value of 0.007 Ω • cm at 67.5% weight loading, which marked the limit of silicone resin workability. For EMI shielding purposes, commercial conductive elastomer materials using nickel graphite fillers are typically specified to be less than 0.1 Ω • cm.[1, 3] Plots A and B show that a weight loading level greater than 53% was necessary to achieve volume resistivity of less than 0.1 Ω • cm. The corresponding volume loading scale indicates greater than 22% loading by volume was necessary to attain less than 0.1 Ω • cm.

Conductive fillers that are spherical in shape typically require volume loading levels greater than approximately 35% to achieve volume resistivity values lower than 0.1 Ω • cm.[2, 6] The flake-shaped nickel graphite used in this work attained 0.1 Ω • cm at a significantly lower volume loading level (approximately 22%) as compared to spherical-shaped particles because of the shape factor in particle packing (see Figure 1).

An important consideration for EMI shielding gaskets is the surface contact resistance. Low surface contact resistance is necessary to form good electrical contact between an enclosure flange and the EMI gasket. In addition to loading considerations, flake-shaped particles have an additional advantage over spherical particles because of the characteristic way they "bite" into a flange to produce low contact resistance.

PHYSICAL PROPERTIES: HARDNESS, ULTIMATE ELONGATION AND ULTIMATE TENSILE STRENGTH

The Durometer hardness of conductive elastomers is important when considering the desired compressibility of the EMI shielding gasket. Soft materials are highly compressible, conforming well to mating surfaces and requiring low forces to effect a seal for an enclosure.

The Shore A hardness in Figure 3, plot C shows a strong correlation between filler loading and hardness. For EMI shielding, a practical range for volume resistivity is between 0.01 and 0.1 Ω • cm. The corresponding range of Shore A hardness is 82 to 67; a change of 15 hardness units. Other conductive fillers and polymer systems would have different hardness values, but it is expected that similar trends of rapid increase in hardness with filler loading would apply.

UTS and ultimate elongation are common measures for the strength of conductive elastomers. In use, materials with low UTS and ultimate elongation are more susceptible to damage by compression and do not recover as well from strain.

Ultimate elongation (Figure 3, plot D) rapidly decreased as conductive filler loading increased. In the practical volume resistivity range of 0.1 to 0.01 Ω • cm, the elongation decreased substantially from 510% to 150%. The UTS was not as sensitive to loading as hardness or ultimate elongation. The UTS behavior (Figure 3, plot E) had a linear dependence on weight loading up to 60%, followed by sec-

ond linear region with a lower slope. The UTS changed from 410 to 325 psi over the volume resistivity range of 0.1 and 0.01 Ω • cm. UTS in the low slope region decreased from 335 psi to 319 psi (a difference of only 16 psi) but covered a large portion of the useful volume resistivity range of 0.023 to 0.07 Ω • cm.

BALANCING ELECTRICAL AND PHYSICAL PROPERTIES

The plots in Figure 3 show that hardness increased and tensile strength decreased as filler loading increased. By adjusting the loading level of the filler, a conductive elastomer may be "tuned" to adjust hardness or strength properties to suit specific EMI gasket specifications. However, by adjusting the amount of filler, a stronger and softer gasket would rapidly lose conductive properties as the loading of the filler is decreased. Conversely, if the elastomer were loaded to produce very low volume resistivity to optimize shielding effectiveness, the material would become comparatively hard and would exhibit lower elongation and tensile strength. Mechanical and electrical properties are interdependant variables of conductive filler loading that work against one another. As such, an appropriate loading level for a conductive filler is based on a compromise between the desired physical and electrical properties of the EMI shielding gasket.

REFERENCES

1. "EMI Shielding for Commercial Electronics." Chomerics, Div. of Parker Hannifin Corp. Issued product catalog 1999.
2. "Correlating DC resistance to the shielding effectiveness of an EMI gasket." Thomas Clupper. *ITEM* 1999. Robar Industries, West Conshohocken, PA.
3. "Engineering Design and Shielding Product Selection Guide." Instrument Specialties Co., Inc. Issued product catalog.
4. Randall M. German. *Particle Packing Characteristics.* Metal Powder Industries Federation, Princeton NJ: 1989.
5. Joel S. Hirschhorn. *Introduction to Powder Metallurgy.* American Powder Metallurgical Institute, New York: 1969. pp 72–80.
6. Robert B. Rosner. "Conductive materials for ESD applications: an overview." *Conformity,* Volume 6, No. 99: 2001. pp 33–45.

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