PARTICLE - SIZE COMPACTION AND ITS EFFECT ON CONDUCTIVE COATINGS, ADHESIVES AND INKS

While conductive coatings, inks and adhesives have been on the market for the last 5 to 10 years, little information has been provided on how they are made, and more importantly, why the differences in how they are made are important to the end user. There are basic differences in the pigments and resins used, additives incorporated and the processes where they are made into the final product. Since this technology of producing conductive coatings, conductive adhesive and inks for EMI and RFI shielding is rarely discussed, many people are at a loss to explain why products perform differently from one another. This article provides a basic format from which one can analyze different conductive materials.

Types of pigments, particle size, amorphous structure, porosity, shape, layout properties in resin vehicles, degree of loading, particle compaction and dispersion additives were researched and evaluated.

These factors are particularly important when analyzing the mechanism of electrical current conduction through the pigment and resin media which has been combined to make up a conductive shielding coating. The resistance offered by the particles is determined by the length of the chains which can be formed with these particles in a resin media. A more important factor is the gap that exists between the particles after the coating is applied.

The degree of pigment loading, and the manufacturing process which compacts the pigment particles to ensure uniform particle size and particle contact has a dramatic effect on conductivity. Initial conductivity is affected, as well as service parameters such as heat stabilization of the product, environmental resistance and attenuation values.

PIGMENT

The conductive material utilized will have a strong impact on the surface resistivity as well as relative attenuation levels. Table 1 shows how the pigment selected will affect performance. The grade and purity of the pigment will also affect the shielding ability.

Material	Typical Applied Dry Film Thickness	Ohms/Square at applied D.F.T.
Silver	1.0 mils	0.1 - 0.3
Copper	2.0 mils	0.4
Nickel	2.0 mils	1.0
Graphite	2.0 mils	7.0

Table 1. How Pigments Affect Performance.

Other factors which often receive less attention are the particle size, structure, contained volatiles, and porosity of the pigment. These issues are particularly important with copper, nickel and graphite pigments. The mechanism of current conduction through these pigments involves the resistance offered by the particles and the length of the chains which can be built up with these particles. Therefore structure is important, as it determines the gaps that exist between particles and particle chains. Theory indicates that these gaps must be less than several millimicrons for the electrons to flow on to the next particle efficiently. Electrons can jump such a gap through a phenomenon known as electron tunneling. If the gaps are wider than a few millimicrons, the electron flow breaks down, and the conductive system (or) conductive coating rapidly becomes nonconductive. For best results in conductive coatings utilizing the pigments mentioned above, the following criteria are needed.

Small particle size is required to provide more particles per unit volume and thus less distance between particles. This obviously results in more particle-to-particle contact and greater conductivity and consistency of product. Particle shape has been demonstrated to have less an impact than size, and is therefore not as important for good conductivity. See Figures 1 and 2.

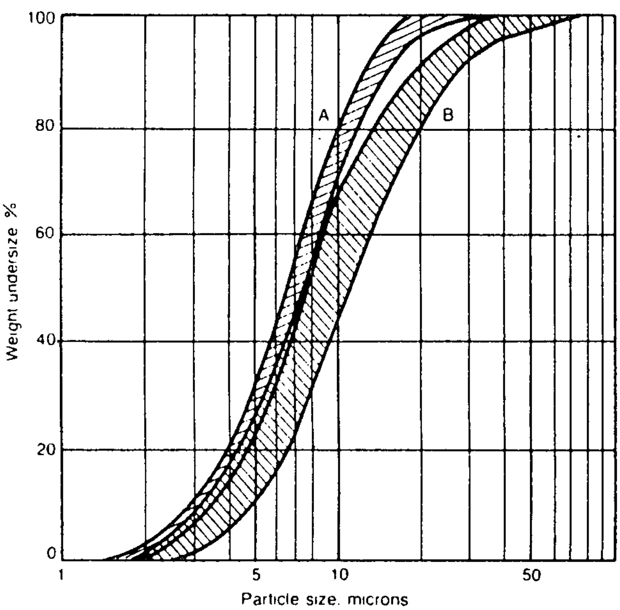

Figure 1. Typical particle size distribution of nickel powders.

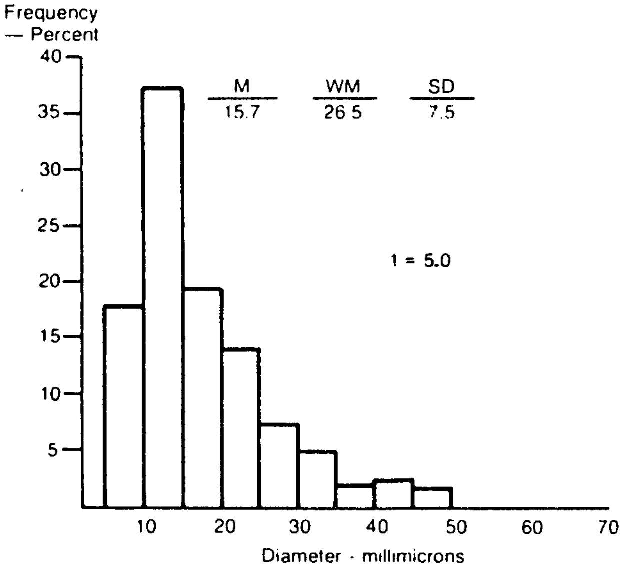

Figure 2. Particle Distribution.

High structure is needed for particle chains and groupings, making the path easier for electrons by reducing the number of insulative gaps which must be overcome through electron tunneling.

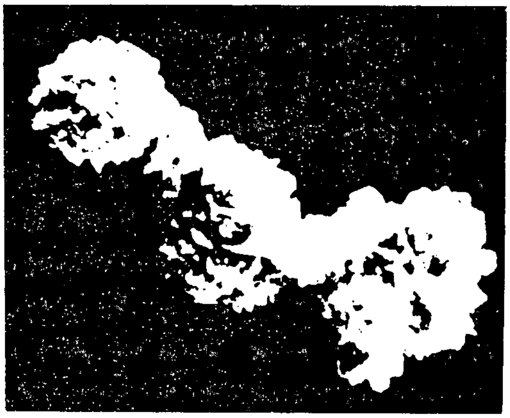

Figure 3. Type 287 nickel powder. Scanning electron micrograph. Magnification x 7.500.

Figure 3 shows how some pigments connect in structured chains rather than random settling. These chain structures enhance the conductivity of the dry film.

High-porosity allows greater particle-to-particle density and surface area per unit of volume. This also allows greater compaction of the particles in a dry film while keeping weight to a minimum, and provides greater surface-to-surface contact between particles. In other words, there is a large surface area relative to the density.

Low volatiles content promotes the tunneling effect and particle-to-particle conductivity. Removal of surface oxygen and carbon groups is just as important to the long-term "environmental stability" of the dry film as it is to the initial conductivity. This is accomplished through calcination in an inert environment and also through proprietary chemical processing. See Figure 4.

RESIN SYSTEMS

Polymer Structure. In general, polymers are electrically insulating and poor conductors of charge. However, polymer structure can and does affect the conductivity of conductive coatings. Polymeric materials are unique because of the range of structural forms that can be synthesized. They can be crystalline materials, amorphous materials, or a mixture of both. As far as electrical properties are concerned, the effect of crystallinity is to lower the conductivity. Some crystallinity is needed for abrasion resistance and heat stability, so one must be careful to select a resin with the appropriate molecular crystallinity.

Curing characteristics. The curing characteristics of a resin system have a major impact on the performance of the conductive coating by determining the solvents which may be utilized for thinning and the settling characteristics of the conductive particle. Since the compaction of the conductive pigments is directly related to the conductivity of the dry film, the resin system must allow for proper settling of pigments. Secondly, through curing and cross-linking of the resin molecules, the conductivity may be enhanced further. The proper curing of the material prevents the entrapment of the solvents which can dramatically alter the conductivity of the dry film. The method of curing has demonstrated this in actual application. Conductive coatings exhibit better conductivity when they are cured at ambient temperatures since this allows for greater settling of particles and hence greater compaction in the dry film. Although forced heat curing is desirable for some production requirements, it will have the slight effect of raising the conductivity of the dry film. This effect can be influenced by the dilution ratio of the paint, choice of solvents, and application technique, but generally, forced curing limits the time in which particle settling can take place.

MANUFACTURING PROCESS

The degree of pigment loading has a dramatic effect on the final conductivity of dry film. To insure good particle-to-particle contact, uniform particle size is important. For best particle-to-particle contact, a large volume of pigment (nickel, copper, etc.) is required. This is difficult to accomplish and still retain good adhesion and abrasion characteristics. Greater degrees of pigment loading can be accomplished with smaller particle size and with the proper selection of resins. Most important however, is the process of blending the resin and pigment together with other stabilizing chemicals to make the high solids content possible. It is easy to see that the volume of conductive pigment in each container of material is directly related to its value to the customer. Some manufacturing processes have been found to provide consistent results with high pigment loading.

The use of roller mills instead of conventional ball mills allows for greater control in the blending and processing of conductive coatings. Controlled pressure can be exerted on every conductive particle to insure more uniform particle size and shape. At the same time, roller mills provide for blending with less shearing, thereby leaving chains of particles intact for better conductive characteris-

Conductive particles prior to chemical processing. Surface carbon and oxygen groups limit conductivity.

Conductive particles after chemical processing. Oxygen and carbon groups eliminated.

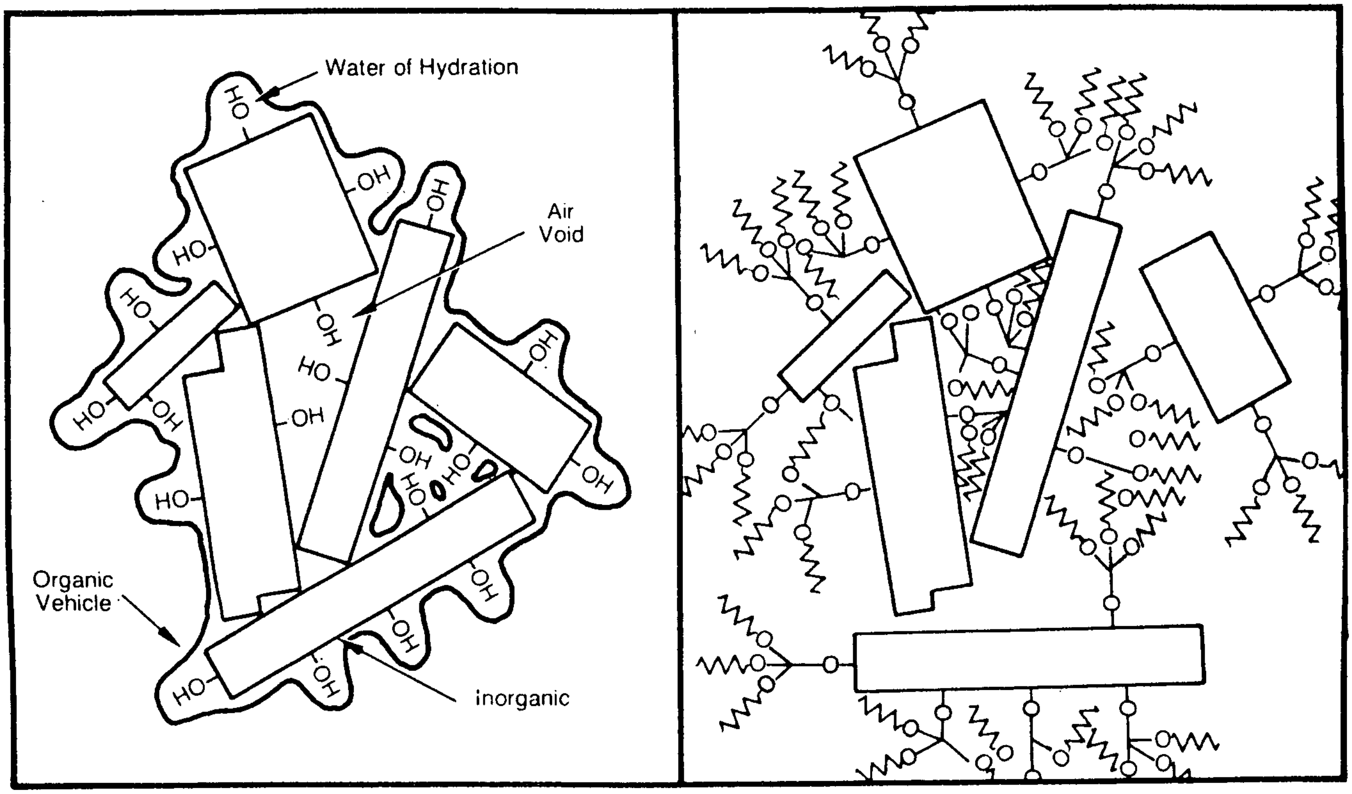

Figure 4. The proposed mechanism for deposition of a monomolecular layer of chemical additive to effect the elimination of inorganic water of hydration and air voids, resulting in deagglomeration.

tics in the dry film. Conventional ball mills accomplish mixing by randomly pounding the pigment with tumbling stainless steel or porcelain balls in an enclosed drum. Roller mills perform this function by rolling the material through two tightly compacted rollers where the pressure is controlled and measurable. This more controlled processing gives greater consistency in the final product and greater repeatability from batch to batch. This process also generates less shearing of the polymer to allow for less disruption of its molecular structure. Most importantly, it also allows for greater loading without sacrificing consistency of small particle size.

TESTING & EVALUATION

A final product is examined to insure that it meets the specifications desired. It involves more than a spray out and checking the electrical properties of the dry film. The solids contact is checked to insure batch-to-batch consistency. This, along with viscosity, pot life, dry time and density are checked on the liquid product. It is then sprayed out to check electrical properties, which are tested with forced heat curing and ambient curing. Most importantly, the stability of the material is examined under harsh environmental conditions.

Humidity Test - 120° F. at 95 percent relative humidity for 72 hours.

Heat Aging - 150° F. for 72 hours.

These tests are indicators of any variance that would appear in a certain batch. Even with the most careful batch preparation and blending, a minor variance can occur in the final product. Through environmental conditioning, any significant difference will be readily detectable. Without such conditioning, such a variance could exist without being noticed.

Overall, one can see that much more is involved in producing reliable conductive coatings which will remain an effective shielding mechanism over the life of the electrical equipment on which it is applied. The proper selection of pigments, resins, and manufacturing processes dramatically affect the performance and consistency of the final product.

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