EMI SHIELDING WITH STAINLESS STEEL FILLED PLASTICS

INTRODUCTION

With the recent FCC regulations governing EMI emissions from electronic devices, manufacturers have been forced to provide varying levels of shielding. The explosive growth of EMI emitters such as computers, printers, typewriters, and communication devices has made sensitive digital electronics increasingly susceptible to interference. To function properly, these appliances may need to be shielded from external EMI. Plastic, once thought of as an electrical insulator, can now be made conductive by compounding in conductive fillers. Thus, plastic can often replace heavier, more expensive and less attractive metal parts where EMI shielding is required. The ability of plastic to dissipate high voltage (4000V+) electrostatic charges can also be improved greatly by making it moderately conductive. Current applications for statically dissipative plastics include components such as boxes or racks for PCB's, and covers for electrical devices used in explosion-proof service. Components that must remain free of clinging dust or contamination due to static charge can be made antistatic by conductive fillers.

Electrically conductive fillers in common use today include powdered and fibrous carbon, metallized graphite and glass, aluminum flake, and stainless steel fiber. Fibers, due to their high length to diameter ratio, are more efficient electrical conductors than powders or flakes, and can be used at much lower loading levels. Stainless steel fibers combine the good inherent conductivity of metals with the efficiency of fibers.

Conductive fillers hold many advantages over coatings such as electroless nickel plate, metal powder filled paints and zinc arc spray. All coatings are prone to scratching, wear or spallation, while fillers are "molded in" thus making them permanent. Coatings can be difficult to apply uniformly to complex components, particularly those with deep recesses, and are a costly secondary operation. Coatings may have cost advantages over fillers on large, heavy housings such as those used in computers and printers where the part has a relatively low surface area to volume ratio.

METAL FIBER PROPERTIES, FORMS, AND SELECTION

For use as a conductive filler, stainless steel fiber is available in Types 304, 316 and 347 alloys in diameters from 4 to 25 microns. Figure 1 shows the effect of varying fiber diameter on shielding effectiveness (attenuation) at a constant loading level of 5 weight percent. Since cost rises dramatically with decreasing fiber diameter, 7 micron is generally the most cost effective for EMI shielding and ESD applications.

Alloy	18/20 Cr—8/12 Ni—2 Mo—1.0 Si max 0.08 C max.
Density	7.9 gm/cc
Ultimate Tensile Strength	210,000 psi (1.45 GPa)
Tensile Yield Strength	180,000 psi (1.24 GPa)
Tensile Elongation	1.2—1.5%
Hardness	38 Rc
Electrical Resistivity	75 microhm cm

Table 1. Brunsmet® Fiber Properties.

Types 304 and 316 are the most commonly selected alloys. Table 1 lists chemical composition and basic properties data for 7 micron 304 stainless filaments. The individual fibers retain the basic properties of the bulk stainless steel and are therefore strong, ductile and corrosion-resistant.

For use in conductive plastics, stainless steel fiber is available in three forms:

- continuous filament on spools (tow);
- sized and chopped;
- airlayed web (nonwoven).

Tow is the simplest form, consisting of continuous strands of multiple end filaments, typically 1159 fibers per strand, wound on spools of 1 to 3 pounds each. Although normally supplied uncoated, tow can be supplied with a variety of sizings which further enhance processability.

Sized and chopped fibers can often be used where compounding continuous tow is not feasible. To make this product, individual strands of tow are coated with 6 to 30 weight percent sizing, then dried and chopped to specified length. A wide range of sizings is available including polyvinyl alcohol (water soluble), polystyrene, styrene acrylonitrile (SAN), nylon, and polycaprolactone (PCL). When selecting a sizing, consideration should be given to its chemical

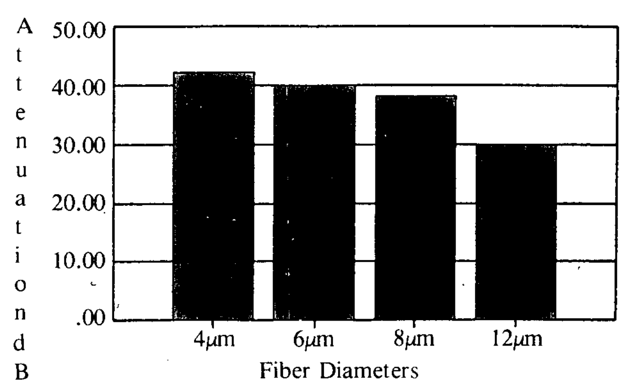


Figure 1. Shielding Effectiveness at 1000 MHz vs. Fiber Diameter, 5 Wgt. % S.S.Fiber.

and rheological compatibility with the base resin. Due to dilution in the base resin, sizing content in molded articles should range from 0.5 to 1.0 weight percent.

Fiber lengths in use currently range from 3 to 8 mm. In this form, the fiber bundles are nonclumping and can be readily dry blended (batch) with pellet or granular resins prior to compounding. Special feeders may be required when metering pure fiber into continuous process equipment, due to its high bulk and tendency to pack in conventional single and double hollow, helix screw-type feeders.

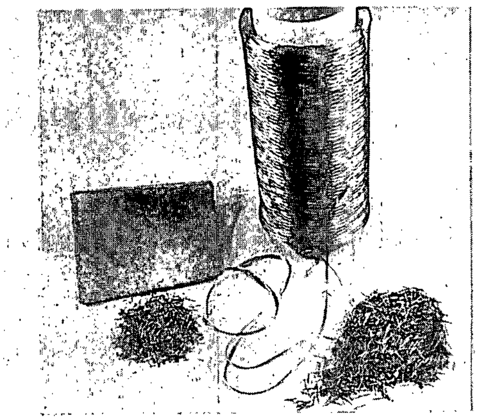


Figure 2. Metal Fiber Forms—(clockwise from top) tow; 0.300 in. long chopped; 0.150 in. long chopped; web.

The last form of stainless steel fiber of interest for conductive plastics is airlayed web. This is a nonwoven, randomly arrayed fiber web weighing from 1 to 12 oz/yd². It is supplied unsized and is used as a conductive veil for bulk molded and sheet products. Some examples of tow, sized chopped fiber, and web are shown in Figure 2.

ADVANTAGES OF STAINLESS STEEL FIBERS

Compared to other fillers, very low concentrations of stainless steel fibers are needed to impart significant electrical conductivity. For a 7 micron fiber, only 5 to 6 weight percent (1.0 to 1.3 volume percent) is required for EMI shielding of 35 to 40 dB. From this, many advantages accrue:

- minimal alteration of base resin properties;
- shrinkage similar to unfilled resins;
- excellent colorability and surface appearance;
- excellent abrasion and corrosion resistance (long life).

Many EMI shielding and ESD applications require engineering resins with high strength and impact resistance. Used in low concentrations, stainless steel fiber fillers have a minimal adverse effect on mechanical properties. Getting comparable shielding with metal powders, flake, or carbon fiber can require up to 40 weight percent loading, causing significant strength reduction. Shrinkage rates comparable to unfilled resins allow existing molds to be used with stainless steel filled compounds without modification of size or draft angles. Wear rates on molds, screws and barrels are reduced compared to other fillers which are abrasive when used at high loading levels.

The ability to color articles with conductive fillers can be critical. When properly molded, stainless steel fibers disperse uniformly enough that crystal resins take on a light grey appearance. Colors such as orange and beige, as well as others, are therefore possible. For critical color matching of housings or other appearance parts, painting may be required. Injection-molded components with smooth surfaces do not show the high gloss attainable with unfilled resins but instead have a satin appearance characteristic of fiber-filled compounds. This effect can be minimized by the use of surface texturing. Because stainless steel fiber is chemically stable and nonoxidizing, components filled with it will not age (increase resistivity with time), or lose shielding effectiveness due to abrasion, chipping or peeling. This is important in critical shielding applications where coating degradation would create EMI leaks, or chips could short out sensitive circuits.

The disadvantages of stainless steel fibers center on processability and cost. To be effective in enhancing conductivity, it is essential to maintain a high aspect ratio. When compounding and molding resins containing fibers, a balance must be struck between complete dispersion of the individual fibers, which tends to break them, and incomplete dispersion, which reduces conductivity. The cost of stainless steel fibers can eliminate them from consideration in parts that are large and bulky. This type part may be better shielded by using aluminum flake or coatings, if these meet all the functional requirements of the design.

THREE MAJOR VARIABLES AFFECTING CONDUCTIVITY

Three variables have been identified as crucial to

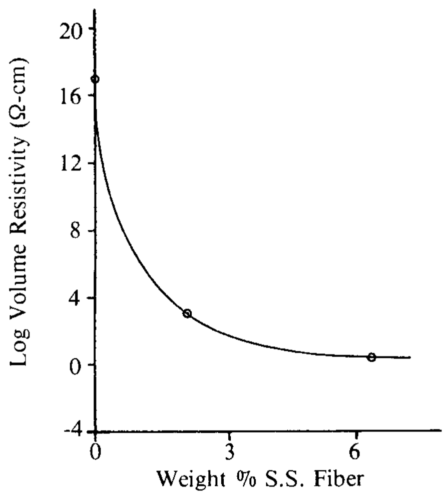
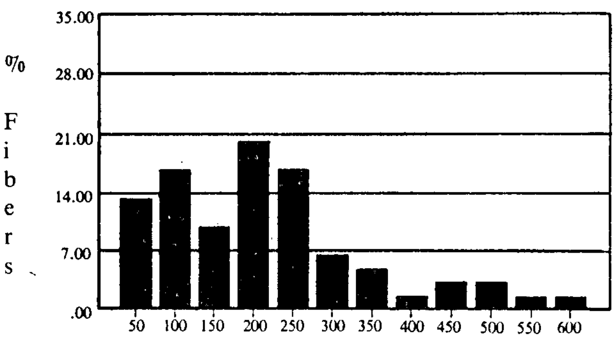


Figure 3. Volume Resistivity versus S.S. Fiber Loading Level (8μ 304 S.S., as molded L/D ~ 200).

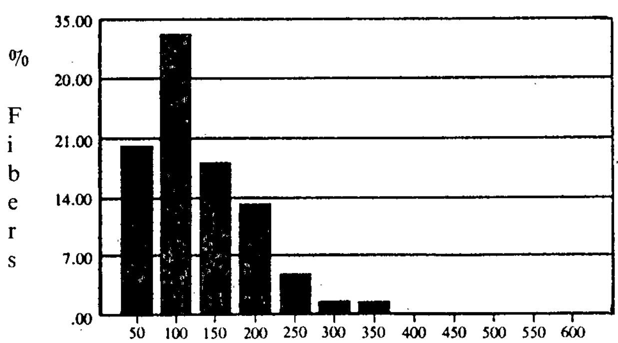
success in molded stainless steel fiber-filled components. These variables must be controlled to achieve good conductivity, shielding effectiveness, physical properties and appearance. They are: fiber length; fiber concentration; uniformity of dispersion.

For a given fiber length and diameter, the concentration of fibers determines the probability of fibers touching and forming a conductive network. Increasing fiber concentration has a strong effect on electrical conductivity up to a critical concentration, after which increases tend to level off.[1] This concept is illustrated in Figure 3. For many common base resin systems, such as polycarbonate and ABS, ESD protection can be attained with about 2 weight percent loading while EMI shielding of 35 to 40 dB requires 5 to 6 weight percent. These loading levels apply when using 7 micron fiber in properly molded articles.

The second, and potentially most important, variable in achieving conductivity is fiber length or aspect ratio. Aspect ratio (L/D) is a dimensionless ratio defined as fiber length divided by fiber diameter. It is critical to conductivity because it determines the length of the path an electron must travel before reaching another fiber or insulating resin. At a constant concentration, the higher the L/D, the higher the conductivity.



(A) Aspect Ratio of S.S. Fibers in 37 dB Plaque.



(B) Aspect Ratio of S.S. Fibers in 17 dB Plaque.

Figure 4.

This was shown through analysis of fiber length in injection-molded plaques[2] containing 6 percent 7 micron 304SS fiber. It was found that an average aspect ratio of about 200 (fiber length 0.057 in.) is required to attain the 35-40 dB shielding range. When L/D fell to 120 (fiber length to 0.034 in.), shielding effectiveness fell to 17 dB. The number of long fibers appears to be important as well. Two fiber length distributions are presented in Figure 4; a) indicates a 37 dB plaque, and b) a 17 dB plaque. Fiber length in the acceptable part was skewed toward the long side as indicated by 60 percent of fibers greater than an L/D of 200. By contrast, the poorly shielding plaque had only 22 percent of its fiber greater than an L/D of 200. Resistivity of the poorly shielding plaque was about 15 times higher than that of the acceptable plaque.

Dispersion is the last major fiber variable in the shielding effectiveness equation. It is also the most difficult to quantify. For maximum shielding effectiveness at minimum fiber loading, the fiber should be completely and uniformly dispersed in the molded article. In practice, attainment of very uniform dispersion may indicate breakage of the fiber leading to high resistivity and poor shielding results. Nonuniform dispersion (clumping) can also occur with similar poor shielding results and bad surface appearance. A compromise between these two extremes is desirable and can be attained by adjusting compounding and molding variables. Crystal resins allow for easy visual inspection of fiber dispersion when compounding or molding. When opaque resins are used, radiography is helpful in determining uniformity of dispersion. For best results, parts should show slight amounts of clumping, indicating that most of the tow strands have released, but that individual fibers have not been shortened excessively.

PROCESSING AND TESTING METAL FIBER-FILLED PLASTICS

The major applications for stainless steel fiber-filled plastics are in conductive injection-molded parts. For this reason, emphasis in this section will be placed on injection molding and on compounding prior to molding. Ultimately, the success or failure of a filled component depends on balancing the sometimes conflicting requirements of part appearance, shielding effectiveness and cost. There are a number of choices available to the compounder with respect to incorporating the fibers depending on available equipment.

Stainless steel fiber has been compounded into a number of engineering resins using various extruders and kneaders. A method for incorporating glass fiber, both chopped and continuous roving, using a twin-screw extruder is described in an article by Werner & Pfleiderer Corporation.[3] With some experimentation, it is possible that these same processes could be used for stainless steel fiber. This particular extruder had been modified especially for compounding with fiber reinforcements, thus making introduction of the filler very simple. The work of Buss-Condux Corporation[4] has yielded good results incorporating chopped (0.3 in. long) stainless steel fiber in polycarbonate, ABS, and modified PPO (Noryl®) resins. Regardless of the equipment type used, when compounding chopped stainless steel fiber it is important to minimize shear in order to keep fiber breakage to a minimum. This is usually accomplished by adding the fiber downstream of the main inlet of the extruder so that the fiber joins the polymer in its molten state. Proper selection of sizing as regards to resin compatibility and melting point is very important. Sizing should melt and release the individual fibers from the strand for good dispersion, but should not melt so soon as to cause excessive fiber length attrition. Experimentation with screw geometry, screw speed, stock temperature, pellet size, and other variables may be necessary to yield a conductive compound.

Injection molding thermoplastic resins containing stainless steel fibers is similar in concept to other fillers. Conventional reciprocating screw injection molding machines have been used very successfully with existing molds that were designed for unfilled resins. The screw L/D and compression ratio have a strong influence on the degree of fiber dispersion and breakage. In a study of glass-filled thermoplastics, Schweizer[5] found that nearly all fiber breakage occurred during plastication prior to injection. This appears to be true for metal fibers as well. Molding experience to date has shown high stock temperature, low back-pressure, and long shot times tend to produce components with best conductivity. Shear and resultant fiber breakage can be minimized by using full round runners and by using as large a gate size as practical.

Fiber length and concentration in compounding and molding is of such great importance that it should be checked and controlled. The simplest method for checking fiber length is to press a resin pellet or chip between a glass slide and cover plate in a hot press.

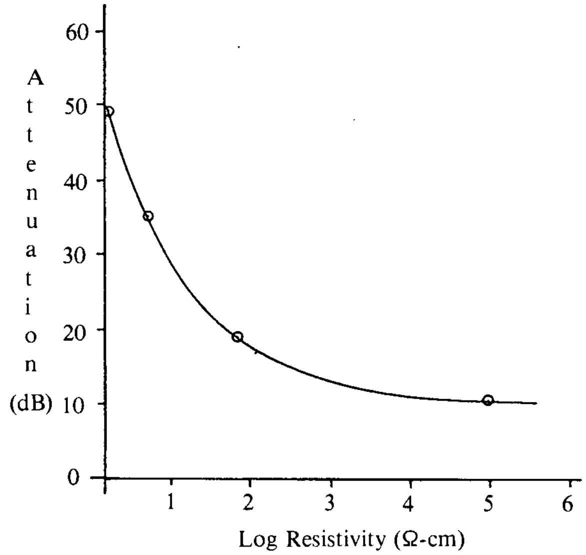


Figure 5. Attenuation at 1000 MHz vs. Resistivity for Injection Molded Plaques.

Measurements are made using a microscope with a calibrated reticle. A more accurate length check can be made by extracting a fiber sample using an appropriate solvent to dissolve the base resin. After thorough rinsing and drying, the fiber can be weighed to determine its concentration or sprinkled on a slide for length measurement. For large numbers of samples, computer image analysis has been used for glass fibers.

The single most important property of conductive plastics is volume resistivity. Figure 5 shows the effect of volume resistivity (ohm. cm) on shielding effectiveness (dB) at a frequency of 1000 MHz. A modification of ASTM D257 is used to measure volume resistivity. The resistance of test panels cut from actual production parts is measured using a low voltage ohmmeter. Silver paint electrodes are applied to the sample's edges prior to testing.

Shielding effectiveness correlates well with volume resistivity for a uniform part. However, it should be noted that it is possible to have low resistivity parts with poor EMI shielding because of fiber lean areas that can cause leaks. This can happen when fiber distribution within a part is inconsistent. For this reason, it is recommended that molded samples be tested in accordance with the new ASTM emergency standard, ASTM ES7-83. This test, using either the dual chamber of coaxial line method, will give the user a good estimate of how well a particular compound will perform in the field under actual use conditions.

CONCLUSION

Stainless steel fibers are easily processed into most thermoplastics to create electrically conductive composites. Significant shielding effectiveness can be obtained at very low loading levels. Because of this, mechanical properties and colorability of these resins is excellent. Fiber aspect ratio, concentration and dispersion must be controlled in the final article to assure conductivity. Some simple test procedures to measure these factors have been developed and correlated to shielding effectiveness.

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