ELECTRICALLY CONDUCTIVE ADHESIVES

A smart solution as alternative for soldering

Electrically conductive adhesives play a vital part in the electro- and electronics industries. These adhesives are the perfect choice for attaching and connecting electrical or electronic components. In a growing number of applications, they are used as a more effective alternative to conventional soldering. Crucial for a successful application is not only the right choice of the adhesive, but also the right curing parameters.

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Electrically and thermally conductive adhesives are usually epoxy or epoxy-resin based adhesives containing metallic filling materials. Silver flakes are primarily used as the filling material. Conductive adhesives are particularly suitable for making electrical contacts on temperature-sensitive substrates such as PET, as their curing temperature lies clearly below soldering temperature. In addition, the adhesives are much more flexible than solder and are therefore better able to withstand vibrations. A further advantage over soldering is that conductive adhesives are lead- and solvent-free.

Generally, there are two types of electrically conductive adhesives: isotropic and anisotropic. While isotropic conductive adhesives (ICA) conduct electricity in all directions, anisotropic conductive adhesives (ACA) contain special conductive particles in the µm range, which conduct electricity through the adhesive layer only in one direction /1/. This article focuses on the isotropic systems only.

Grade, shape, grain size and grain distribution of the filling material are critical influencers to optimizing adhesive conductivity. But one of the most significant, and often overlooked, contributors to conductivity is the adhesive curing process. Thanks to high-tech hardeners, it is now possible to create innovative adhesive systems which cure under water. New conductive adhesives can even provide snap-cure and cure within minutes. Innovative silver fillers allow newly developed conductive adhesives to be dispensed by jetting and screen printing, without clogging the dispenser nozzles. In the narrative that follows, the influences and parameters on conductive adhesive systems will be examined.

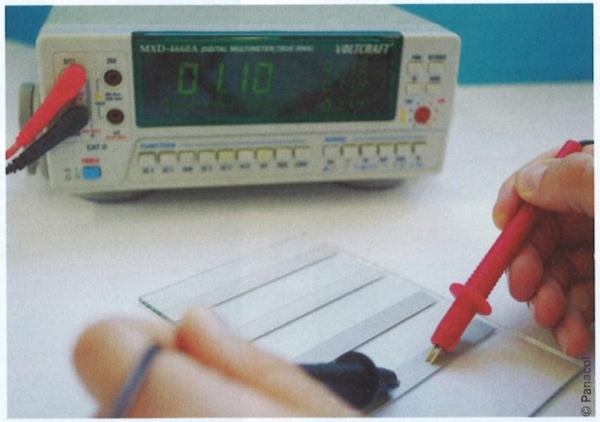

Figure 1: Metering the resistance of a conductive adhesive bead

Measuring conductivity

To describe the conductivity of an adhesive, the specific electrical resistance of the cured adhesive is measured (Figure 1). The following measured data was collected by a defined measuring method: A bead of the electrical conductive adhesive was dispensed by applying one-component adhesives directly onto the substrate (glass) in a defined form (l = 90 mm, w = 10mm and thickness = .25mm) and, according to product specifications, cured. Two-component adhesives were mixed before dispensing and curing. To ensure a uniform thickness of the beads, the adhesives were coated with a coating knife. To measure the specific resistance, the bead was measured in several sections. The electrodes of the measuring equipment were placed in a distance of 10mm each and the resistance in Ωcm metered.

Electrically conductive adhesives

Unfilled adhesives usually feature specific electrical resistances in the range of 10^{12} to 10^{15} Ωcm. By adding metallic fillers these resistances can be reduced to 10^{-3} to 10^{-4} Ωcm. This leads to a major increase in the conductivity of filled adhesive systems. Generally, the fillers consist of metal plates or flakes, which have a characteristic particle grain size /1/.

Pivotal for the electrical conductivity is, first, the filling grade, as the conductivity of the electrical current occurs through direct contact of the metal particles. As a general rule, the higher the number of contacts of the individual particles, the higher the conductivity. It can be observed that the conductivity is low when the number of contacts is low, but increases rapidly with an increasing number of contacts until a maximum value is achieved, which doesn't increase conductivity any further even with addition of more filler material. The filling level, at which a very strong increase in conductivity can be measured, is called percolation threshold (Figure 2) /1/. Second, the conductiv-

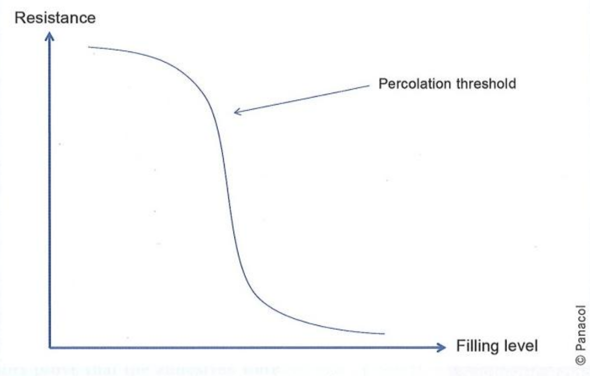

Figure 2: Percolation threshold

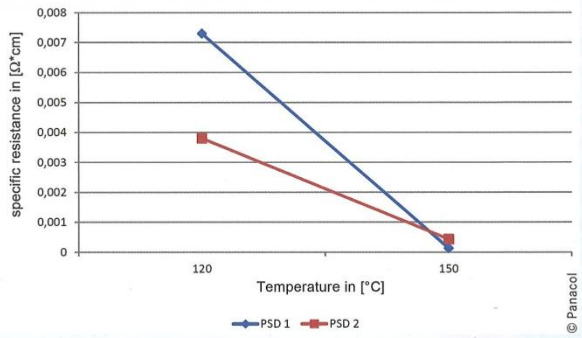

Figure 3: Influence of the particle size distribution on the specific electrical resistance in Ωcm

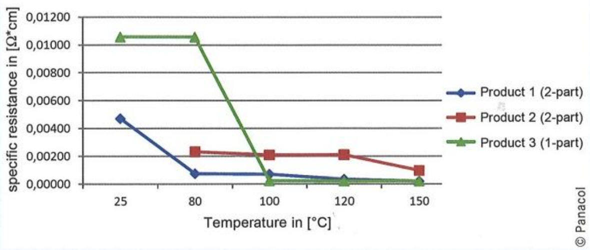

Figure 4: Conductive adhesives in a conductivity range of 10-4 Ωcm.

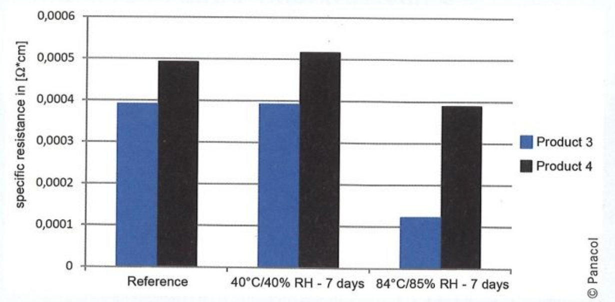

Figure 5: Specific resistance before and after 168 hrs storage at 40°C/40% RH and 85°/85% RH

ity of an adhesive depends of the geometrical form and grain size distribution of the filling materials. The particle size distribution (PSD) of the silver fillers directly influence the electrical conductivity and thus the electrical resistance of the entire system. As shown in Figure 3, a two-component adhesive with two different particle size distribution in the filler at the same filling level was measured. The Figure indicates the specific electrical resistance in Ωcm depending on the curing temperature. The adhesive with particle size distribution 1 (PSD 1) features a distribution of smaller particle sizes than adhesive PSD 2. As PSD 1 and 2 have different filling levels volumetric-wise, the distribution with the coarser values (PSD 2) has statistically more contact points than PSD 1. Thus, PSD 2 features a lower resistance even at a lower curing temperature. With increasing temperatures, the diffusion process in the filler particles can lead to more effective density of the adhesive system and therefore generate a higher electrical conductivity.

Apart from the particle size distribution, the geometry of the particles also influences the percolation threshold. Decisive for the conductivity is the average number of contacts between the particles. Therefore, particles with a corn flake shape and complex shapes are preferred /1/.

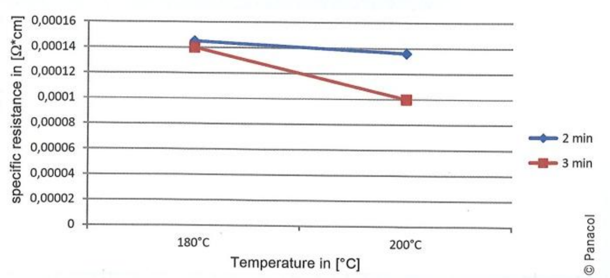

Figure 6: Snap cure with new hardener within minutes

Influence on electrical conductivity

The total conductivity of a high tech adhesive system results from the individual contact resistance between the metallic filler particles (1). Not fully cured residues of the resins or impurities of the metallic filler can lead to oxide layers on the metal particles and thus lead to higher resistance and lower conductivity. Because of this, usually precious metals such as silver are used as filler materials: the silver oxide layers still provide a good conductivity and therefore can be neglected. But every single obstacle in the adhesive leads to higher resistance: in order to flow, the electrical current has to pass these defected areas. Obstacles and defects narrow the electrical flow path, and thus lead to a higher resistance than straight flow paths /3/.

Curing influences conductivity

Another aspect which has a big impact on the conductivity of any adhesive is the curing process. An evenly cured epoxy adhesive reduces the strain in the matrix and also lowers dissimilar resistance in the adhesive layer. Thermal curing of the adhesive produces crosslinking of the base polymer in which the metal particles are embedded. If the curing process is insufficient (i.e. too low curing temperature or too short curing time) the crosslinking of the base polymer is too low, making the base polymer too soft and leading to shifts in the metal fillers by external mechanical influences /1/.

Figure 4 shows clearly a decrease in the electrical resistance in connection with higher curing temperatures. This depends strongly on the curing of the polymer matrix of the epoxy system at corresponding temperature levels. A higher curing temperature usually leads to faster curing and a better stability than lower temperatures /5/. It is believed that individual lattice spacings within the matrix or between the polymer matrix and the metal particles change with different curing temperatures. Hence the polymer matrix is compressed more densely at higher curing temperatures, which produces a denser molecular structure and deforms the distances in the molecular structure or between the polymer chains and metal particles. As a result, several contact points of the filler particles are generated, producing a better flow path for electrical currents. With increasing temperatures, diffusion processes become an important factor to generate a higher electrical conductivity.

Another theory is that surface tensides on the metal particles are reduced at higher curing temperatures and thus do not pose additional obstacles for the current.

One-component adhesive systems need heat, (generally between 125°C and 180°C), to cure /5/. Adhesive product no.3 in Figure 4 shows to be a good example. The product features a very low curing temperature and hardens at only 100°C , while its resistance falls dramatically at the same temperature.

For curing of the conductive adhesive several hardener systems were tested (cationic, amine, and Dicyandiamide) at different curing temperatures. Here, a connection between the selected hardener system and the later conductivity of the cured adhesive was observed.

Influence of humidity

A well-cured adhesive is crucial to prevent humidity related conductivity failure. Water or moisture can react with the polymer matrix in a way that corrupts or destroys the matrix. This can also lead to a shift of the glass transition temperature to lower values, which then increases the risk for thermal damages. In the worst case, water can act as softener and reduce the mechanical stability of the adhesive /2/. If the polymer matrix is expanded due to water retention or due to constant temperature changes, the contact resistance of the filler material is increased. This may result in a failure of the adhesive product /1/.

Climatic influences

The conductivity of the cured adhesives can be strongly affected by climatic influences. Moisture and higher temperatures in particular can influence the adhesive's conductivity. However, new conductive adhesives are more resistant to these variables, demonstrating a decrease in the electrical resistance when tested after exposure (Figure 5), resulting in higher conductivity. These results prove that the adhesives were fully cured without leaving traces of liquid residues such as resin residues. Therefore, no water could be stored in the polymer matrix, which would have led to damages in the matrix and thus increasing the contact resistance of the filler particles.

Curing with water and cold curing

New and innovative adhesives on based on organic resins even go a step further: These conductive adhesives can be cured under water or at cool 5 °C. In addition to the advantages of organic adhesives the curing processes can open up whole new application fields.

Snap Cure

Curing of conductive adhesives used to be a long process. Thanks to newly tested hardener systems many of the 1-part products develop now cure within minutes at high temperatures. Figure 6 shows the curing times of a tested product and its respective specific resistance in Ωcm. Thus it appears that this adhesive is fully cured within two minutes at 180 °C.

Application

As shown above, the composition of the filling material has a major impact on the conductivity of the cured adhesive. Furthermore, the filling material also

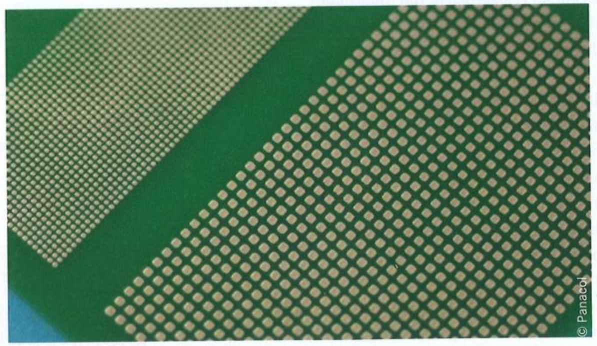

Figure 7: Screen printing

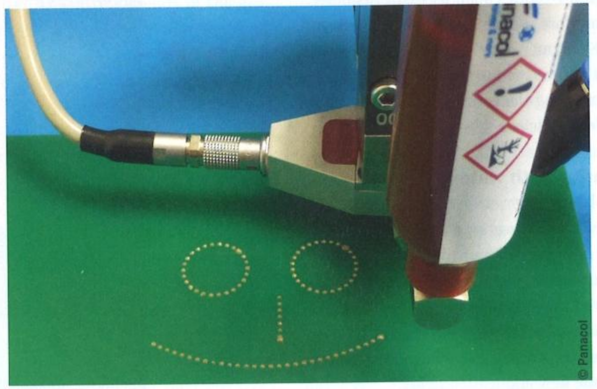

Figure 8: Jetting

influences the viscosity of the adhesive. Adjusting the viscosity is a decisive factor for applying the adhesive through jetting or screen printing. Too low a viscosity leads to bleeding or to instability of the adhesive edges in screen printing, too high viscosities lead to failures in applying the adhesive. A high viscosity can also block the nozzles of jet valves. Apart from the viscosity, the homogeneity of the adhesive is an important factor. A homogenous filled adhesive prevents sedimentation of single filler particles and a separation of the material during application. For optimal application, an optimum in the viscosity, the filling level and the homogeneity is needed. A homogenous distribution of filling material in the adhesive, together with constant curing conditions lead to the best conductivity results /1/.

Conclusion

Many parameters influence the conductivity of the cured adhesives. New technologies and new fillers open up new possibilities for conductive adhesives, or for specially formulated adhesives for individual applications. The new adhesives can even be used for innovative applications including organic adhesives, climate-resistant expoxies, snap cure adhesives or application via jets or screen printing (Figures 7 and 8). ■

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