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Applications of thermal analysis in an electronics manufacturing environment [1]

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Abstract

Analytical instrumentation can be very useful in dealing with many types of situations commonly experienced in an electronics manufacturing environment. Advanced Interconnection Technology (AIT) is involved in the development, licensing and manufacture of several different types of discrete wired interconnection products. At AIT, we have extensively utilized instrumental materials characterization techniques, such as thermal analysis, in the development and application of polymeric materials in diverse types of sophisticated electronic interconnection systems.

Using an example of an actual manufacturing situation as a framework for reference, this paper will describe how one can utilize thermal analysis as a method for controlling polymeric materials. In addition, it will demonstrate the effectiveness of modern analytical instrumentation in the efficient resolution of complex problems.

INTRODUCTION

Thermal analysis is utilized at AIT in connection with the development, licensing and manufacture of several different types of discrete wired interconnection products. The manufacturing process and materials of construction of a discrete wired circuit board are similar to those of a conventional printed circuit board with several significant differences. Whereas a conventional circuit board utilizes etched traces of copper to form the circuit paths, a discrete wired circuit board, shown in Fig. 1, uses insulated fine-gauge copper wire positioned in a precise pattern by a computer-controlled machine [1]. Although some conventional circuit board materials are used, the discrete wired circuit board is manufactured using several unique materials.

The generation of circuitry by "writing with wire" is a key aspect of the discrete wiring technology. An interesting application of materials charac-

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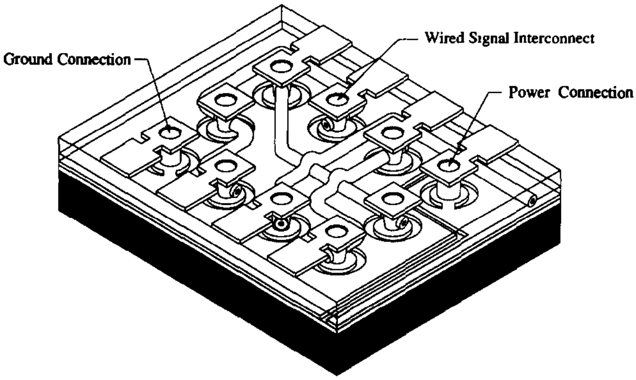

Fig. 1. Discrete wired circuit board.

terization at AIT involved a manufacturing problem whose first symptom was the blistering and delamination of an epoxy prepreg used to encapsulate the circuit wiring.

The initial observations seemed to indicate that the problem was related to the wire, because the delamination was observed only around the wiring. Samples of the suspect wire and a control, were submitted to our laboratory for analysis. The objective was to determine quickly the cause of the delamination because manufacturing was halted until the problem was resolved. Once the cause was found, the development of a quality control procedure would be necessary to prevent a repeat of this incident.

EXPERIMENTAL

A TA Instruments 951 TGA and a 9900 Computer were used. A 1 m length of each wire sample, weighing approximately 50 mg, was used for each run. The TGA was heated at 10°C min^{-1} in a nitrogen environment while the weight loss versus temperature curve was recorded.

A Nicolet Instruments 5 SXB FTIR, with a DTGS detector, and a Spectra-Tech Horizontal ATR, with a 45° ZnSe crystal, were used. The wire samples were formed into a sort of ribbon cable and clamped firmly against the ATR crystal. A spectrum was acquired by averaging 256 scans at 4 cm^{-1} resolution.

A Nicolet Instruments TGA Interface II coupled to the 951 TGA was also used. The TGA interface cell and the transfer line were equilibrated at 250°C. A 500 mg sample of the wire was heated in the TGA at 10°C min^{-1} in a nitrogen atmosphere. FTIR spectra were collected consecutively by averaging 16 scans at 8 cm^{-1} resolution. The Nicolet Specific Infrared Detector (SID) software was used for data collection and to analyze the resulting spectra.

A Perkin-Elmer TMS-2 was used in the initial analysis of the problem. A TA Instruments 2940 TMA was utilized in the development of the control procedures and subsequent routine quality control (QC) testing. Both instruments used a helium purge, a 20°C min^{-1} heating rate and a knife-edge flexure probe with a 0.10 N load.

RESULTS AND DISCUSSION

The first step of the analysis was to determine that the adhesive was of the correct type. Given that the correct adhesive was used, we then planned to look for and identify any possible contaminants. The FTIR spectra of the two wire samples were obtained using the procedure described. As seen in Fig. 2, the spectra appear quite similar, indicating that the correct adhesive was used. However, upon close inspection, a difference was noted.

An absorption peak at 1660 cm^{-1} was observed in the suspect wire spectrum and not in the control spectrum. This absorption is typical of the carbonyl group of the solvent NMP, 1-methyl-2 pyrollidinone, used to coat the adhesive on the wire. In an attempt to generate a spectrum of the possible contaminant, the control spectrum was subtracted from the suspect spectrum. Unfortunately, the results were not conclusive.

TMA has been used to characterize the cure of wire insulation coatings [2]. TMA was used to monitor the curing reaction by measuring the softening points of the coatings. In this situation we applied the technique to a thermoplastic adhesive coating rather than a thermoset insulation coating. TMA of the suspect and control wire samples, Fig. 3, showed a

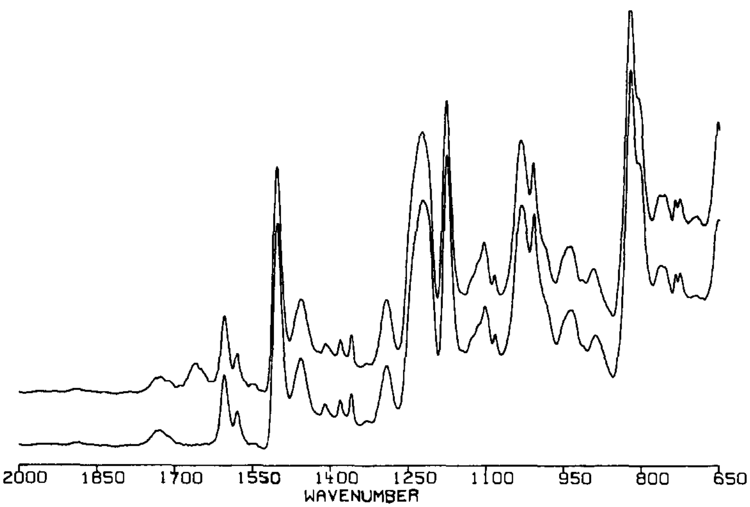

Fig. 2. FTIR spectra of suspect wire sample (upper) and control wire sample (lower).

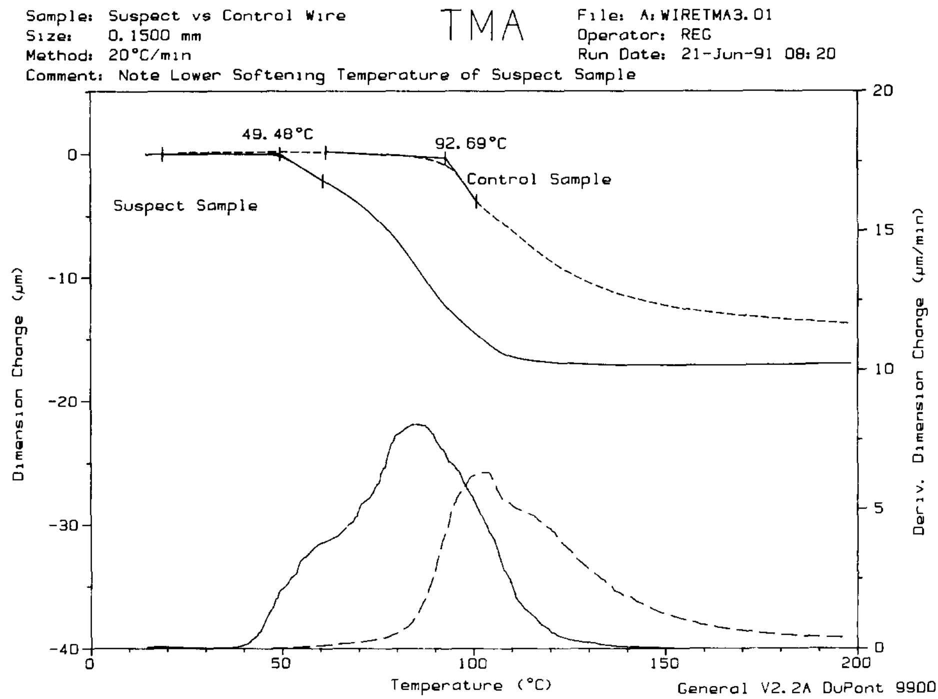

Fig. 3. TMA of suspect wire sample vs. control wire sample.

very low softening point of the adhesive coating on the suspect wire, over 40°C below the control wire. Because the FTIR spectra indicated possible contamination with coating solvent, it would appear that the lower softening point might be due to the plasticizing effect of the residual solvent in the coating.

As seen in Fig. 4, TGA of the wire samples indicated that 0.6% residual volatiles were present in the suspect wire, while 0.0% was found in the control wire. This is a considerable amount of volatiles if one considers that the adhesive coating accounts for only 10% of the total weight of the wire sample. This information is consistent with the FTIR and TMA results, and would be expected to cause the type of delamination observed in manufacturing. Although it seemed apparent that the adhesive coating on the wire was contaminated with residual coating solvent, a confirming analysis was desired.

An evolved gas analysis of the suspect wire sample, obtained by coupling the TGA to the FTIR, provided the confirmation we were seeking. The spectra collected during the TGA/FTIR experiment described earlier were used to generate a Gram–Schmidt reconstruction, Fig. 5. The reconstruction curve indicated a single peak evolving at the same temperature as that at which the TGA weight loss was observed. It was interesting to note that the location and the shape of the reconstruction curve was very similar

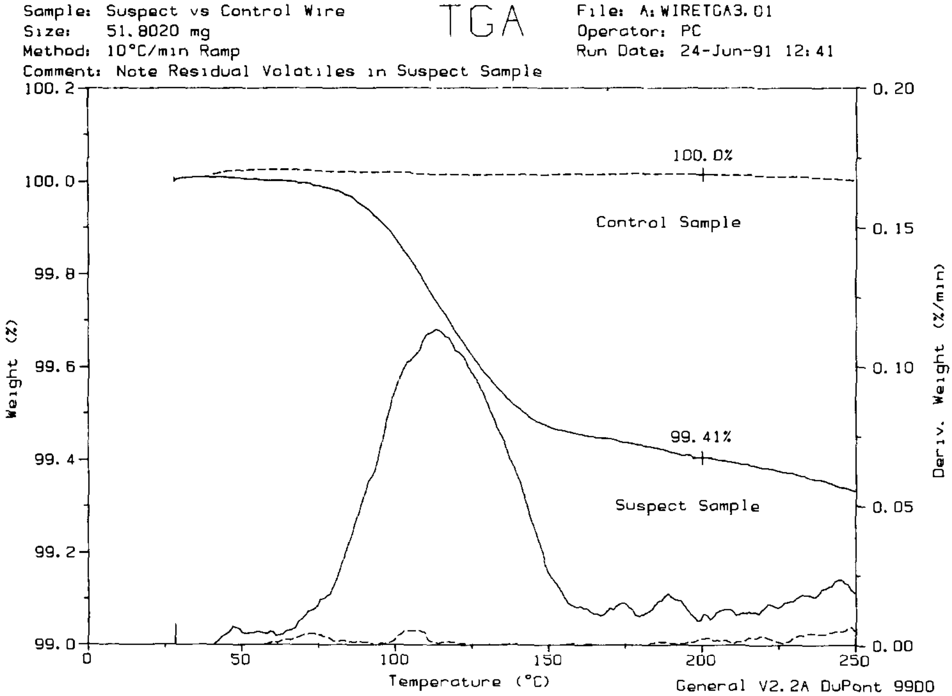

Fig. 4. TGA of suspect wire sample vs. control wire sample.

to the TGA derivative weight-loss curve. Using the Nicolet SID software, it was determined that the peak was due to only one component. A spectrum of that component was generated and searched for against a library of

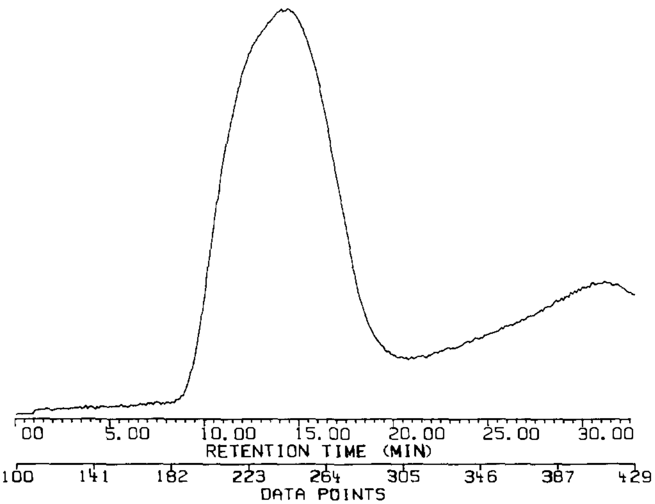

Fig. 5. Gram–Schmidt reconstruction of suspect wire sample.

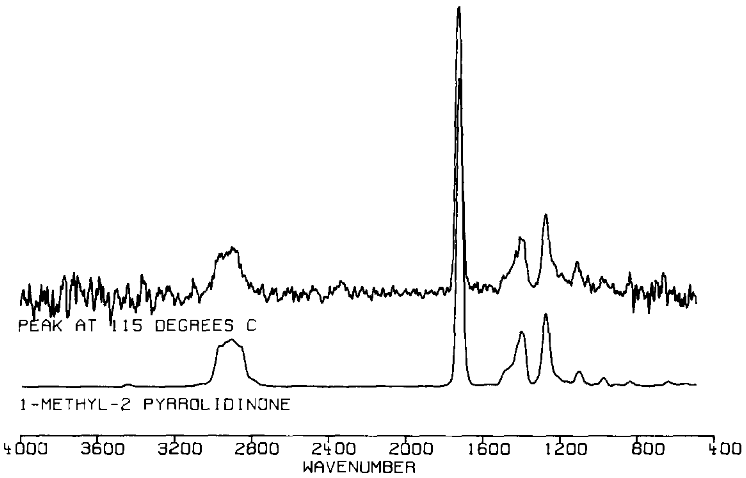

Fig. 6. FTIR spectra peak at 115°C compared with that of NMP.

vapor phase spectra, Fig. 6. A conclusive match, NMP, the solvent used to coat the adhesive on the wire, was obtained. Corrective action to remove the residual coating solvent from the wire eliminated the delamination problem.

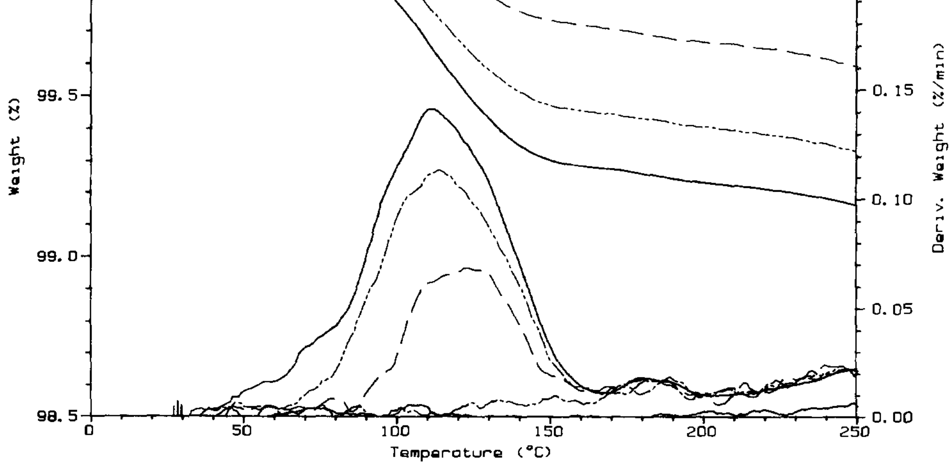

Fig. 7. TGA of wire coatings with varying amounts of residual solvent.

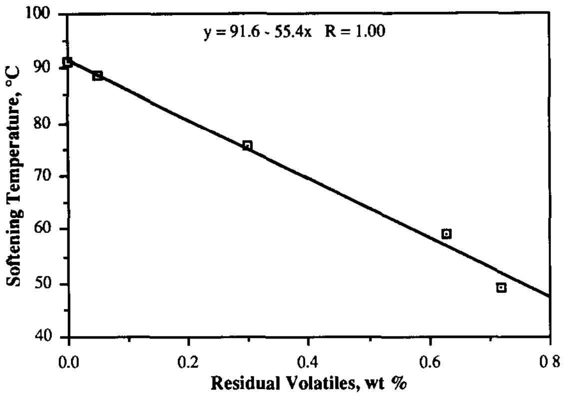

Fig. 8. TMA softening temperature of wire coatings vs. residual volatiles.

The second objective of this investigation was to develop and implement control procedures to prevent a repeat of this incident. Wire was coated with adhesive with varying levels of residual solvent. The samples were then characterized using TGA, TMA and FTIR. The data demonstrated the usefulness of these analytical techniques.

As seen in Fig. 7, the TGA results obtained show clearly the ability of the technique to detect low levels of volatiles in a sample. The softening temperatures of the wire coatings were determined using TMA and were found to be directly related to the level of residual solvent in the coating, Fig. 8. Both of these thermal analysis techniques were shown to be effective methods of evaluating the residual volatiles in this type of sample.

The TMA technique was chosen as an incoming quality control technique, primarily due to throughput considerations. Both TGA and TMA were found to be of sufficient sensitivity for our needs; however the TMA

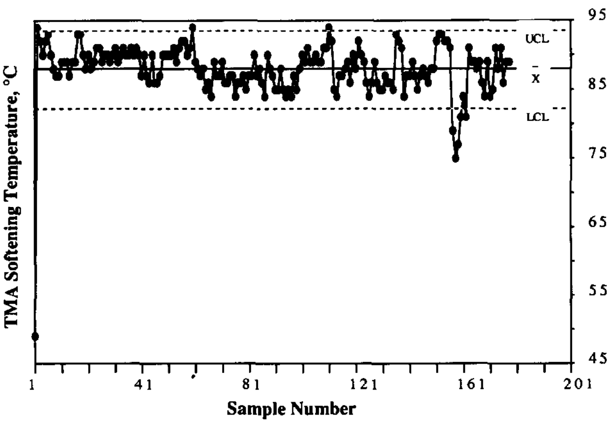

Fig. 9. TMA softening temperature of wire coatings: control chart.

analysis time was only 9 min, compared to 25 min for the TGA. Because the FTIR technique required careful calibration for reliable quantitative results it was not used in this QC application.

The TMA softening temperature test procedure was used for both in-process and incoming material testing. As seen in Fig. 9, a control chart used by incoming material inspection, wire with a low softening temperature was detected during incoming inspection. Subsequent TGA/FTIR indicated that the wire was contaminated with residual coating solvent. The material was rejected and another serious manufacturing situation was avoided.

CONCLUSIONS

Thermal analysis has been found to provide useful tools for the quick solution of manufacturing problems and for the development of quality control procedures. After a serious circuit board delamination problem had halted manufacturing, TGA and TMA quickly detected residual volatiles in fine-gauge wire coatings. TGA/FTIR then identified the volatiles as residual solvent from the wire coating process. Corrective action was promptly initiated at the wire coating vendor and material without residual solvent was produced and used without incident.

The characterization of samples of wire coatings intentionally prepared with various levels of residual solvent was used to develop a quality control test procedure. TGA provided precise values of the residual solvent content of the coatings. The softening temperatures of the coatings were found to be directly related to the residual solvent content. The TMA procedure was considerably faster than the TGA or the TGA/FTIR, and was selected for in-process and incoming quality control test procedures. After a considerable amount of routine testing, low softening temperatures were detected during incoming inspection of a shipment of wire. TGA/FTIR confirmed the presence of residual solvent, the wire was returned to the vendor and another unpleasant manufacturing situation was avoided.

REFERENCES

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