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THERMAL PROPERTIES OF NOVEL CARBON AND GLASS FIBERS BASED HYBRID COMPOSITE FOR PRINTED CIRCUIT BOARDS

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Abstract: The paper aims to present a novel composite hybrid structure based on carbon fibre-glass fibre combination manufactured with the purpose of being used as printed circuit board material in high temperature environments. The composite structure was developed to aid the thermal management in the PCB design and several experimental measurements were carried out to retrieve the effective CTE. The latter was recovered by using a DIL 402 PC device from Netzsch GmbH (Germany) by setting different thermal regimes such are: monotonic increase up to 150^{0}C, cycling up/down to/from 150^{0}C. Statistical data processing will aid the thermal properties measurements.

1. INTRODUCTION

Multiphase polymeric composites have found a niche into engineering applications as materials for structural components in aero-space (e.g. rocket nozzles, fuel tanks), civil engineering (e.g. liquid tanks, panels, pillars), mechatronics (e.g. electronic packaging, sensors, actuators), electrical (e.g. electrical contacts, electrical shields), automotive (e.g. drive shafts, cylinders, brake rotors) or manufacturing (e.g. bearings, pistons) industries.

All the engineering applications of these multiphase polymeric composite materials require controlled thermal expansion characteristics in order to match those of other components and low values of the property to attain a good dimensional stability. With respect to the stability issue, this can be viewed from two perspectives: a change in the geometrical form – materials’ CTE (i.e. CTE - coefficient of thermal expansion) is playing a key role and a change in mechanical properties – a mismatch between the constitutive has a dominant effect [5-7, 10].

The fundamental knowledge on the CTE material properties defines and uses three different types of coefficients of thermal expansion: linear, superficial and volumetric. These CTE coefficients are constant only over specific temperature intervals and are defined function of this temperature range. With respect to the composite materials, there are difficulties in predicting, through modelling, the CTE property due to the constitutive – either fibres or particles – embedded into another type of material who has its own behaviour subjected to the same environmental conditions.

The paper aims to present an experimental based approach of the thermal properties, namely CTE of a hybrid polymer composite structure made up from unidirectional carbon fibres and random, long E-glass fibres, subjected to different thermal regimes. The heterogeneous structure was developed to replace the existing PCB materials due to its tailored material properties and to lower the manufacturing cost of these panels. The hybrid structure was developed based on intrinsic material properties of the carbon fibres whose CTE has a negative value. The herein research was based on the niche opened in the area of multiphase materials with tailored properties that can reveal an everlasting challenge.

2. EXPERIMENTAL RESEARCH

This section describes the materials used to manufacture the composite samples, specimen preparation methods, testing procedure and experimental observation made during the investigation.

2.1 Materials

The multiphase composite samples were manufactured as having three phases – random and unidirectional fibres embedded in a different volume fraction into a polymeric matrix. The matrix material is commercially known as Synolite 8388 P2 from DSM Composite Resins (Switzerland), a polyester resin type.

The fibres used were as following: E-glass type random fibres, commercially available under the MultiStrat^{TM} Mat ES 33-0-25 trade name (from Johns Manville, SUA) and unidirectional carbon fibres under the Panex 35 trade name (from Zoltek, Hungary). The reference samples contain the same number of layers but the reinforcements that were used were only E-glass fibers.

2.2 Testing procedures and devices

The CTE measurements were performed using a DIL 420 PC differential dilatometer from NETZSCH GmbH (Germany). The particle-fibre reinforced multiphase composite samples were shaped into rectangular bars of about 5x5x25 mm^3. For all samples, the transversal external surfaces were polished to guarantee plan-parallel surfaces for precise positioning within the measuring head.

The samples are positioned horizontally on two quartz beds. The measured experimental data were sent to a PC via an USB cable, the acquisition software – Proteus Analysis (from the same manufacturer) - displaying information regarding the thermal strain variation with the imposed thermal range. Further experimental data manipulation allows linear or technical CTE retrieval vs. temperature range or time.

The temperature variation was set up having different trends in time, with a heating rate of 1 K/min, into a static air atmosphere. To eliminate the systems' errors, the dilatometer was calibrated by measuring a standard SiO_2 specimen under identical conditions.

The thermal regimes imposed were as follows, successive heating (2 thermal cycles) being imposed for all the multiphase polymeric composite samples:

- linear – monotonically rise from 20^{0}C up to 150^{0}C
- multi-step– monotonically heating and cooling up/down to/from 150^{0}C.

3 RESULTS AND DISCUSSION

Figure 1 shows the measuring head containing the thermocouple positioned in the sample neighbourhood along with the quartz beds and push rod used to hold the polymeric composite samples, whereas in figures 2 and 3 are being plotted the experimental retrieved curves – the overall thermal strain and effective CTE temperature variation for the hybrid fibre-fibre composite samples experiencing successive thermal conditioning based on a linear heating-up and multi-step heating and cooling, respectively.

As it can be seen for the first thermal cycle (dashed lines, green), close to 60^{0}C, the effective CTE variation is experiencing an abrupt variation due to the glass transition of the polymeric matrix. The polymer chains get broken and rearrange themselves as the temperature rise and the samples were afterwards removed from the oven.

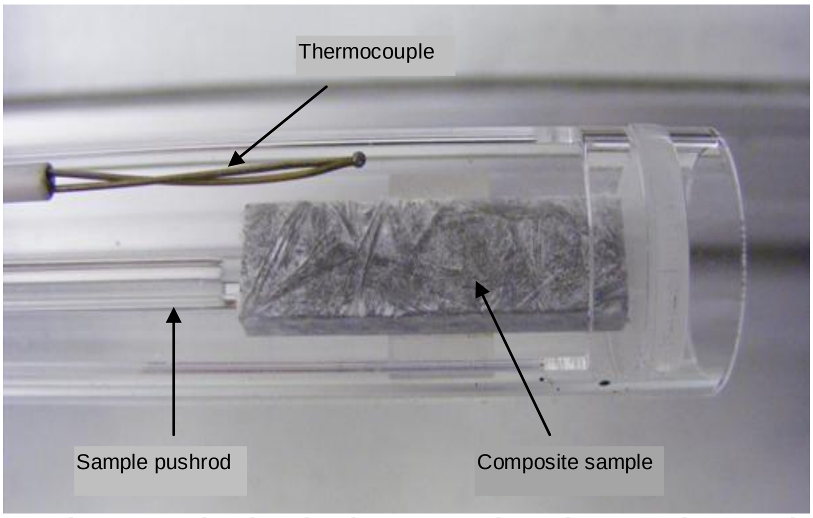

Fig. 1 The measuring head – thermocouple and composite sample positions

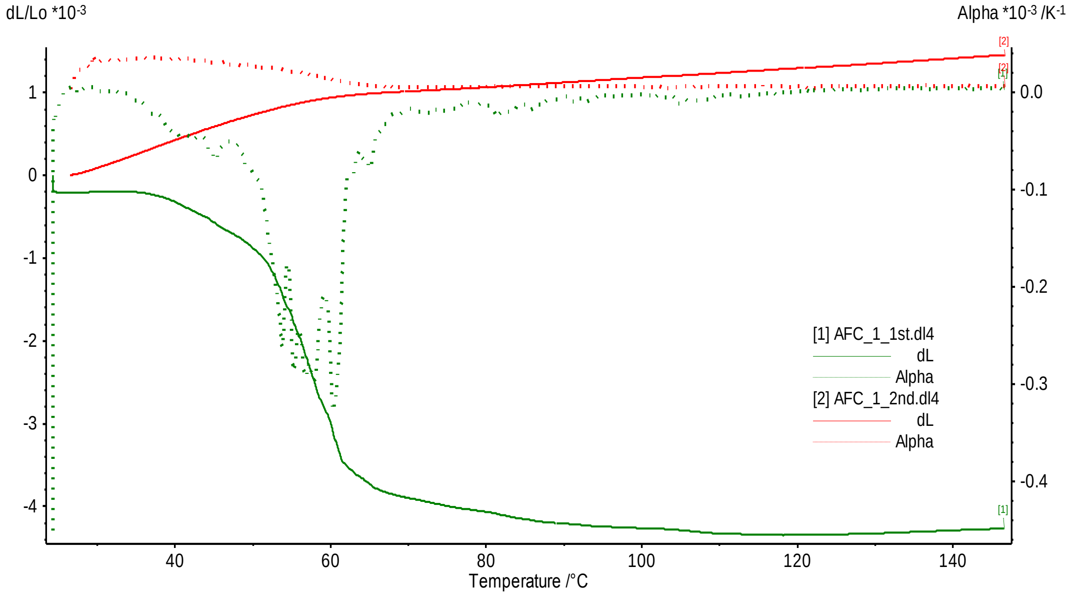

Fig. 2 Instantaneous thermal strain field and effective CTE temperature dependence for the hybrid composite structure subjected to succesive linear heating cycles

These modifications in the polymer chains are revealed in the temperature behaviour of the composite samples during the second heating cycle.

With respect to the multi-heating process, the effective CTE variation with the temperature reveals a more stable process, with the exception of the first applied thermal regimes where the aforementioned take place. Like in the previous case, where a linear heating was applied, in the first thermal cycle the polymer matrix reveal its influence in the temperature interval of 50^0C to 70^0C. Supplementary, a further analysis on the second thermal cycle reveals the fact that the first thermal regime can act as an ending-polymerization process or as a thermal treatment. This means that in applications where the environment is temperature dependent the products made from composite materials, such is the one proposed herein, a previous conditioning to remove the polymer influence must be imposed.

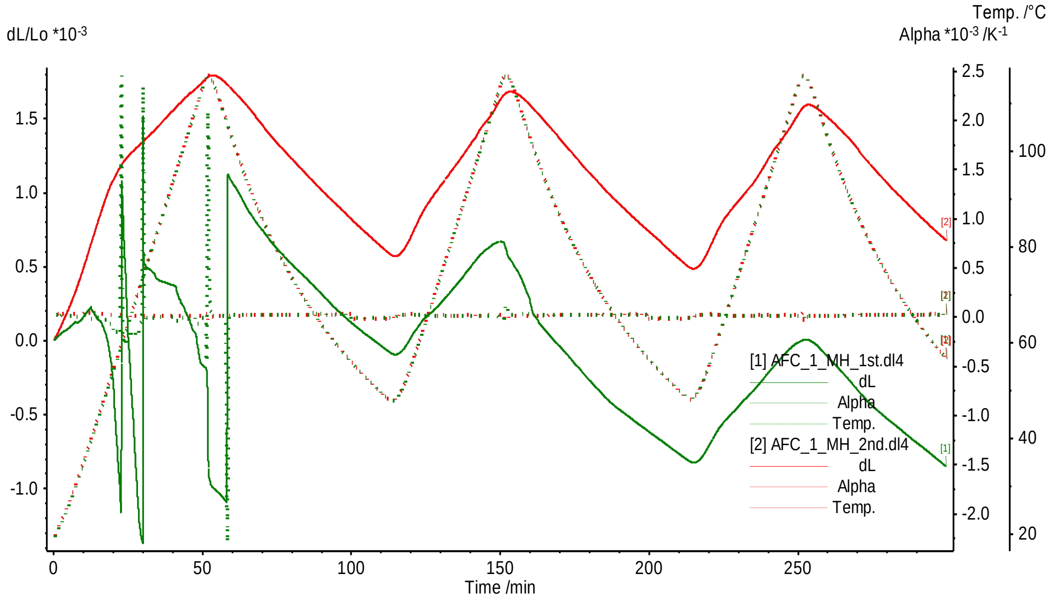

Fig. 3 Instantaneous thermal field and effective CTE time dependence for the hybrid composite structure subjected to succesive multi-heating cycles

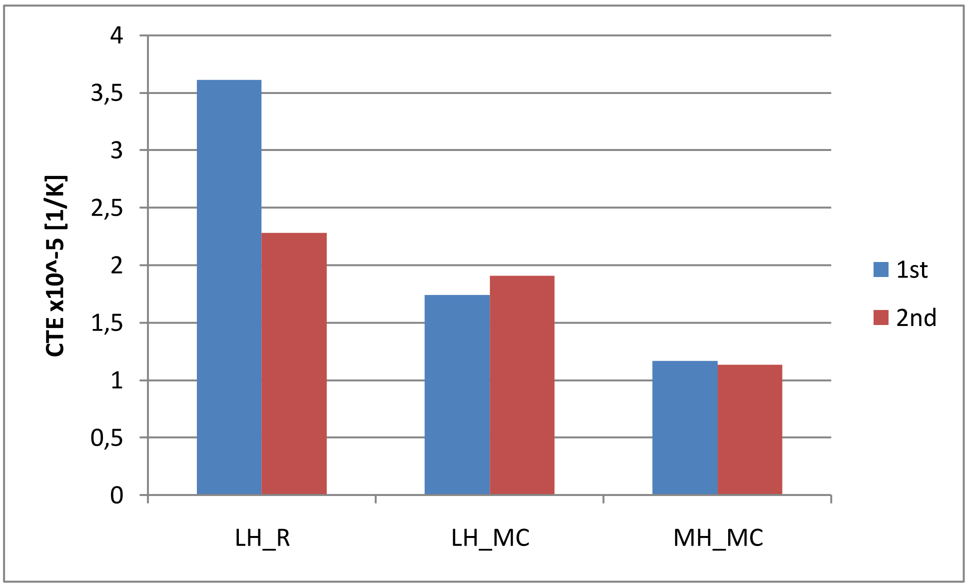

Fig. 4 CTE mean values recorded in succesive thermal cycling applied on the reference and multiphase polymeric composites (LH_R – linear heating, reference sample, LH_MC – linear heating multiphase composite, MH_MC – multiheating, multiphase sample)

In figure 4 is being represented the mean values of the CTE in case of the hybrid structures subjected to various thermal regimes as well as the values recorded for a reference composite sample having the same number of layers, made solely from E-glass random, long fibers.

As it can be seen from the previous figure, the types of the thermal regimes as well as the number of these are influecing the overall CTE of the composite samples, either two- or multiphase. The second thermal working cycle applied (labeled in Fig. 4 with 2nd) upon the composite samples are responsible for the polymer recristalization process and structural kinetics and is not being influenced by the glass or carbon reinforcements.

For the same composite configuration, the different thermal regimes lead to differences in the overall CTE, with almost 45%. These differences can be regarded to the thermal regime imposed, a dynamical one, but without imposing a recovery time while reaching the extremum (minumum or maximum temperatures). This can be the major cause for the discrepances in the recovered CTE value of these composite samples.

Taking into account the fact that these type of materials were design for PCB printed boards it may be concluded the fact that these proved to be relatively thermally stable and the multi-heating environments (switch on/off electronic devices) do not resemble the herein thermal regime imposed, which can be ranked as an aggresive one. In real environments the maximum working temperature do not reach values such is the 150^0C value imposed herein, that can be considered an extremum and should be avoided.

5. CONCLUSIONS

The instantaneous coefficient of linear thermal expansion in case of a multiphase polymeric composite material is not an invariant value being very sensitive to the heterogeneities and thermal regimes at which is subjected the measured sample. Its temperature dependence reflects phase changing, degree of polymerization, differences in internal structure, external environmental conditioning and the evolution of the internal thermal strain. The multi-heating thermal cycles can be carefully chosen and must allow recovery steps between the extreme values of their dynamic variation. Inclusion type, volume fraction, size and distribution within the overall composite structure have their influences on the predicted and experimentally measured CTE values. Reference data may be further considered only for the reinforcement materials even this may be a little difficult to accomplish.

Further studies are under development on multiphase composites made of different combinations, arrangements, particle sizes or fibre length, different thermal regimes. Thermal management issues can be addressed after thermal properties measurements on these multiphase composite structures based on a tailoring process for different combinations among the phases, theoretical predictions and an optimization approach.

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