

SIZING THE MICROSTRUCTURAL INFLUENCE ON THE CTE'S VARIATION IN CASE OF PARTICLE REINFORCED POLYMERIC COMPOSITES

Motoc Luca, D. & Soica, A.

Abstract: *The paper aims to present a comparison approach, from theoretical and experimental perspectives, of the CTE (e.g. Coefficient of Thermal Expansion) and the influencing factors on the thermal behaviour (e.g. manufacturing conditions, material structural influence, etc.) in case of the well known class of particle reinforced polymeric composite materials. The materials were manufactured using a self-developed technology and are made up as a particle reinforced combination, the fillers used being from different materials (metal, ceramics) and different particle sizes, embedded in different volume fraction into a polymeric matrix.*

Key words: particle, polymer, composites, CTE, microstructure

1. INTRODUCTION

Coefficient of Thermal Expansion (CTE) is the material property of primary influence on dimensional stability as it represents the materials response to changes in temperature. Consequently materials with low CTE are highly desirable for precision structures under different environmental conditions where thermal gradients and temperature fluctuations could cause substantial change in dimensions.

The paper herein focuses on the CTE prediction and measurement of samples belonging to the class of particle reinforced polymeric materials. These composite samples were developed and studied primarily with the aim of developing a new force/pressure sensor configuration [1], and next, several other applications, like sensors and actuators, were identified.

The CTE was retrieved considering different temperature cycles but a linear variation up to a temperature higher than the temperature of glass transition particular to the polymeric matrix. The experimental values were compared with those retrieved by using few micromechanical based models developed in the technical literature such are the Kerner, Turner or Tummala-Friedberg enabling to identify and size the major influencing factors on this material property [2-5].

2. THEORETICAL MODELS

Technical literature provides several theoretical models to aid the CTE prediction for any combination of particle reinforced composite materials. Among these the Kerner, Turner or Tummala-Friedberg emerged as new theoretical models developed especially for this composite class.

According to the Kerner model, the composite's CTE can be predicted by using the following relationship:

$$\alpha_c = \alpha_m V_m + \alpha_p V_p + \frac{V_m V_p (\alpha_p - \alpha_m) (K_p - K_m)}{V_m K_m + V_p K_p + \frac{3}{4G_m} K_m K_p} \quad (1)$$

whereas, based on the theoretical model developed by Turner, the composite's CTE represents a relationship between the properties of each phase:

$$\alpha_c = \frac{\alpha_m K_m V_m + \alpha_p K_p V_p}{K_m V_m + K_p V_p} \quad (2)$$

The other theoretical model used in the paper is the one developed by Tummala and Friedberg:

$$\alpha_c = \alpha_m - V_p \frac{\left(\frac{1 + \nu_m}{2E_m} \right) (\alpha_m - \alpha_p)}{\frac{1 + \nu_m}{2E_m} + \frac{1 - 2\nu_p}{E_p}} \quad (3)$$

In all previous expressions, α_c stands for the effective CTE of the particle reinforced composite material, expressed in K^{-1} , α_p and α_m for the individual phases (particles and matrix) CTE's, expressed in K^{-1} , whereas V_p and V_m are the phases' volume fraction. The mechanical properties of each constitutive are being present in terms of the bulk moduli, K_p or K_m , expressed in GPa, or as Young longitudinal moduli, E_p or E_m , expressed in GPa. Supplementary, ν_p and ν_m stands for the Poisson ratio of each constitutive, particle and matrix material.

3. EXPERIMENTAL RESEARCH

3.1 Materials

Samples were manufactured using a self developed manufacturing technology, the phases – particles (SiC and Al) and the polymeric matrix (epoxy 040T resin) being chosen after several trials on different types of metallic particles (e.g. Cu, Fe etc.) and different polymeric resins. The epoxy 040T was chosen due to its good adherence at the particles surfaces. The additives used were chosen as being chemical compounds showing compatibility with the other phases and allowing polymerization process initiation and development.

3.2 Experimental investigation

The composite samples (5x6x25 mm) were subjected to 2 successive heating cycles under a temperature imposed program, using a DIL402 C device, from NETZSCH, Germany.

The effective coefficient of thermal expansion, thermal strain or technical coefficient of thermal expansion of each class of composite materials and their temperature dependence were provided directly by the testing machine software called Proteus. The experimental investigations were done using the following settings for each cycle: temperature program from 20 °C to 250 °C, heating rate 1 K/min, followed by cooling in the oven during 24 hours. Oxidation processes are scarcely due to environment control inside the furnace.

4. RESULTS AND DISCUSSION

Figure 1 reveals the microscopic structure of the Al particles reinforced polymeric composite samples. The structure is highly porous as it was seen microscopically and visual after cutting the composite block. The pores influenced the temperature variation of the experimental curve, as it can be seen from the Fig. 3 representing the thermal behaviour in terms of strain (dL/L_0), even in the second heating cycle in which the gas accumulation within the closed cells representing the pores was impossible to be avoided due to the high content of particles (80%). Figure 2 is being associated with the theoretical predictions of CTE vs. particle volume fraction in case of Al particles embedded within the epoxy matrix.

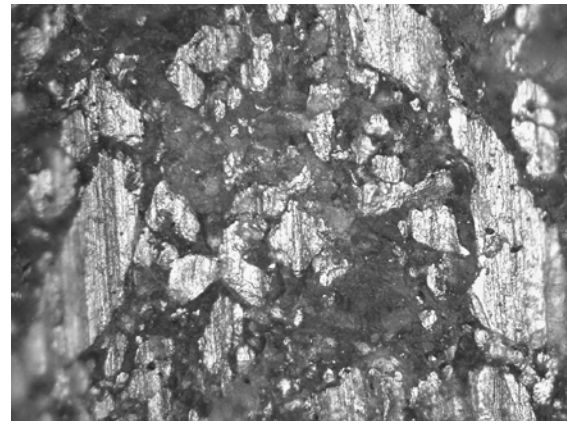


Fig. 1 Microscopic view of the Al particles reinforced polymeric composite sample (x500)

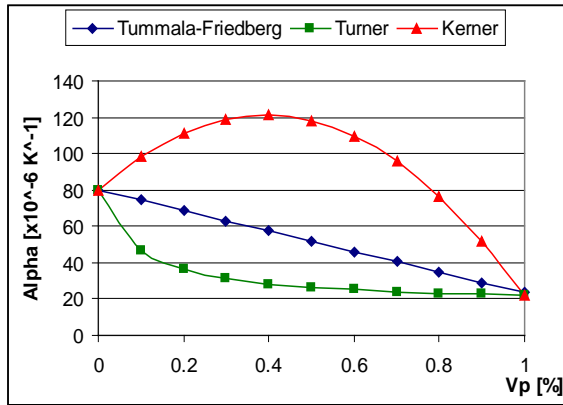


Fig. 2 Theoretical predictions for the Al particles reinforced polymeric composite

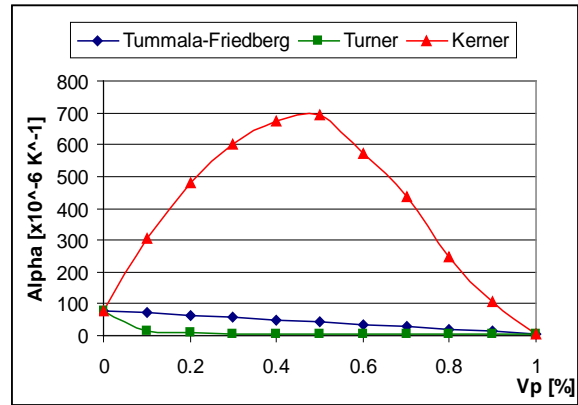


Fig. 5 Theoretical predictions for the SiC particles reinforced polymeric composite

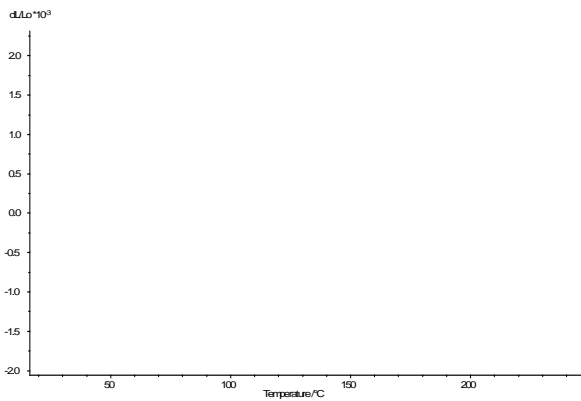


Fig. 3 Thermal strain vs. temperature corresponding to 2 thermal cycles applied upon a 80% Al particles polymeric reinforced composite

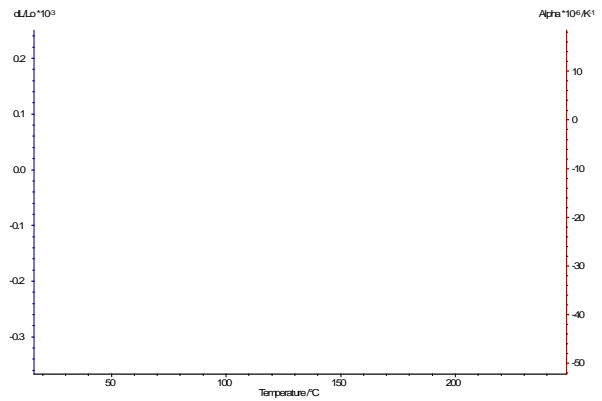


Fig. 6 Thermal strain and CTE vs. temperature variation corresponding to 1 thermal cycle applied upon a 70% SiC particles polymeric reinforced composite

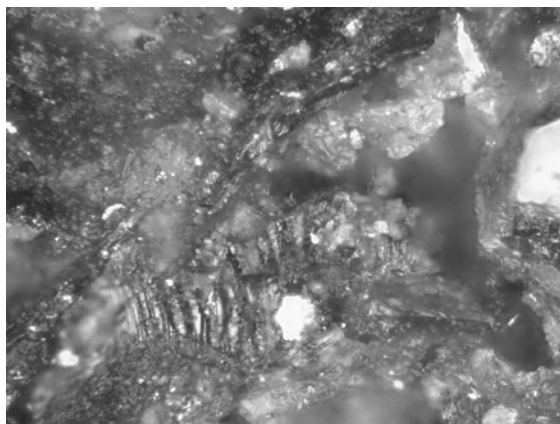


Fig. 4 Microscopic view of the SiC particle reinforced polymeric composite sample (x500)

As it can be seen from the Fig. 3, even in the second cycle (the higher variation curve) the presence of the inner cavities (closed pores) are influencing the thermal strain behaviour inside the composite.

With respect to the second combination, SiC particles embedded having 70% volume fraction within the same polymeric matrix, in figures 4, 5 and 6 are being shown the microscopically view with a 500 magnification, the theoretical predictions of the effective CTE as well as the thermal strain and CTE distribution with temperature during 1 thermal cycle.

Sample	1 st cycle (x10 ⁻⁶ [1/K])	2 nd cycle (x10 ⁻⁶ [1/K])
80% Al composite	5.59	7.89
70% SiC composite	26.56	34.36

Table 1 CTE values retrieved for each particle reinforced polymeric composite investigated sample

In Table 1 are being given the CTE mean values for each class of particle reinforced composite sample investigated. As it can be seen the experimental values are getting closer to the predicted values based on the Turner theoretical model. A more consistent theoretical approach has to be developed to take into account the porosities volume fraction.

The CTE experimentally retrieved values were recovered as a mean value, the peaks points being removed from the statistical data analysis. These extreme values can be regarded to the polymeric chain rearrangements and at temperatures higher than the polymeric glass transition temperature (aprox. 120 °C) to the chain broken, as well as to the inner cavities within the composite samples that are gas concentrators.

5. CONCLUSION

As it can be acknowledge the thermal expansion of particle reinforced composites, quantified by instantaneous coefficient of linear thermal expansion (CTE(T)) is the result of several material parameters: the type of constitutives (phases), the microstructure of the matrix, the particle volume fraction and distribution within the matrix, the porosity volume fraction, the thermal history and finally, but not last, the internal stresses between the phases due to their CTE mismatch.

Thermal cycling are very important for the composites, either particle or fibre reinforced, or even mixed, due to the fact that the engineering applications of this class of materials often imply a fluctuating temperature environment or extreme environments.

The CTE represents an important material property that has to be included in the modelling (e.g. finite elements/volume elements) or numerical simulations during the development of new emerging engineered composite materials.

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6. REFERENCES

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7. ADDITIONAL DATA ABOUT AUTHORS

Assoc. Prof. Eng. Motoc Luca D., Ph.D., "Transilvania" University of Brasov, Precision Mechanics and Mecatronics Department, 29 Eroilor Av., 500107, Brasov, Romania, danaluca@unitbv.ro, <http://www.unitbv.ro>, (+) 40 268 413000 ext. 168.

Assoc. Prof. Eng. Soica A., Ph.D., "Transilvania" University of Brasov, Autovehicles and Engines Department, Faculty of Mechanics, 29 Eroilor Av., 500107, Romania, soica@unitbv.ro, <http://www.unitbv.ro>, (+) 40 268 413000 ext. 154.