Thermal expansion properties of fused borosilicate syntactic foams

Z. Salleh[1*], M. M. Islam[2], J. Epaarachchi[2], Y.A. Ahmed[1]

[1)] Universiti Kuala Lumpur, Technical Foundation Section, Malaysian Institute of Marine Engineering Technology,
Dataran Industri Teknologi Kejuruteraan Marin, Bandar Teknologi Maritim, Jalan Pantai Remis
32200 Lumut Perak, Malaysia.
[2)]Centre for Future Materials (CFM) and School of Mechanical and Electrical Engineering, Faculty of Health,
Engineering and Sciences, University of Southern Queensland, Toowoomba, Queensland 4350, Australia.
Phone: +605-690-9000; Fax: +605-690-9091

[*]Corresponding e-mail: zulzamri@mimet.unikl.edu.my

Keywords: CTE; TMA; composites; syntactic foam; porosity

ABSTRACT – The coefficient thermal expansion, α (CTE) of glass microballoon/vinyl ester syntactic foam was determined using dimensional changes of a temperature gradient plot. The CTE was measured and found to be up to 53-63 % lower than the vinyl ester resin matrix when mixing with different weight percentages of the glass microballoon ranging from 2 wt.% to 10 wt.% using a thermomechanical analyzer (TMA). The results of CTE showed that it has a strong relationship with the syntactic foam density (ρ), radius ration (η) ,cavity porosity (ϕ_γ) and matrix porosity (ϕ_μ). Experimental results showed that the CTE decreases when glass microballoons are added into the composites measured at different temperatures ranging from 30 °C to 70 °C. The CTE from the experimental results were also compared with Turner's modification model for composites for its suitability for thermal expansion of syntactic foams. The results indicate that Turner's modification model exhibits a close correlation with the reduction up to 80 % of CTE based on experiment.

1. INTRODUCTION

Hollow glass microballoon particles when mixed with a resin matrix can be considered as a closed cell foam or syntactic foam. Previously a lot of works that has been carried out on particular syntactic foam characterized the mechanical properties, and also physical properties such as density, volume fraction, wall thickness and porosity [1-4]. Physical properties such as density syntactic foam, including a radial wall thickness ration, porosity and voids are most likely to be very effective in tailoring mechanical properties of syntactic foam [5]. This type of lightweight materials is useful for aerospace [6], marine, thermal insulation and packaging [7] because of their good mechanical properties for the environment. It will lead to a concern subject to high temperatures and thus it is important to determine the coefficient of thermal expansion, α (CTE) [8]. Determination of CTE between the insulation and the substrate is important for use in electronic packaging and thermal insulation because it is necessary to reduce thermal stress and possible failure between two surfaces [8]. Meanwhile, the CTE has also been studied extensively in the aerospace shuttle particularly in the fuel tank to reduce the possibility of failure due to thermal stress [8]. An extensive study was also conducted on the characteristics of CTE of PU foam used as insulation for pipes and cooling gas cooler vehicles [9].

Meanwhile the report on other fillers such as glass microballoon did not include many findings on CTE in the literature review. In the recent study, Shunmugasamy reported that CTE is decreased for three different types of glass microballoon [8]. Another study by Park et al. also showed that CTE is lower than neat epoxy resins for different glass microballoon weight percentage (0-2 % by weight) [10].

Yung also revealed that the reduction of CTE was reported for different volume fractions of glass microballoon mixed with epoxy resin in syntactic foam [11]. Therefore, these findings were not reported clearly about CTE relationship with the physical characteristics of glass microballoon especially porosity and voids are likely to have the same results with ceramic microballoon. In this study, the gap will be investigated to understand more deeply the effect of CTE of the glass microballoon. In order to improve the understanding of this relationship, several models have been introduced for the purposes of this study. Shunmugasamy et al. have found that Kerner and Turner model is suitable to be used for comparison with the experimental results of CTE [8]. In his literature, he also revealed that some models can estimate a CTE of the particulate composites.

Gunes et al. (2008) also reported that several shape memory polymer (SMP) composites exhibited their CTE are comparable with theoretical model [12]. Turner as the founder of this model also assumes that the filler is considered as an isotropic material and thus CTE will not depend on the physical properties of the filler itself [13]. The report also found the changes in the dimensions of the constituent material having the same bulk specimens when associated with temperature, while Kerner with other co-founder of the polymer composite model estimated the CTE considering for shear and isostatic stress occurred in particulate phase composites [14]. Generally, both models used the thermosetting polymer composite matrix resin where CTE is closed to the experimental results within the scope of the wall thickness parameter.

Thus, the theoretical and experimental approaches will be used in this study to link the CTE with different weight percentages of glass microballoon (2-10 % by weight) in syntactic foam. All physical parameters of glass microballoon will be taken into account, such as syntactic foam density, wall thickness, radius ration, porosity and voids content towards developing the use of lightweight materials for the application of thermal stability.

2. RESEARCH METHODOLOGY

2.1 Investigation on Thermomechanical analysis (TMA)

The linear dimension at different temperatures for the thermal expansion characteristics of the prepared specimen were evaluated by a thermomechanical analyser (TMA) using TA Instrument (Model TGA Q500), as shown in Figure 2.1. An expansion type probe was used to measure the temperature-dependent dimensional changes. A preload loading of 0.02 N was applied in all tests. A minimum of 3 coupons were prepared for each compositions. The samples were cut into pieces with dimensions L: 3 mm x W: 3 mm x t: 2 mm. The external gas air input was used for cooling the TA unit system after finishing the testing. The heating rate in each run was kept at 3 ^{o}C/min and the temperature range was changed from ambient to 80 ^{o}C. Time, temperature and change in specimen height were recorded during the test. The slope of tangent, also called coefficient of thermal expansion (CTE), between Dimension change-temperature plot was determined and predicted as shows in Equation (1) (Shunmugasamy et al., 2012, Kim et al., 2011).

$$\alpha = \frac{1}{l} \times \frac{\Delta l}{\Delta T} \qquad (1)$$

where   initial length of specimen, slope of the graph.

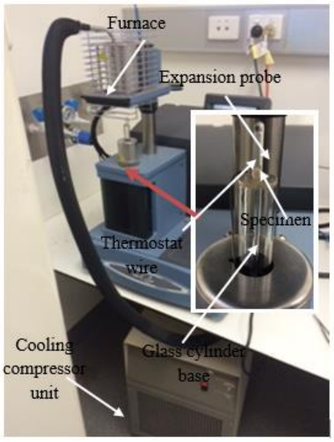

Figure 2.1 Overview of the TMA analyser machine

2.2 The Coefficient of thermal expansion (CTE) model, α

Kerner's and Tuner's models have been modified from previous reports by Shunmugasamy et al., (2012) to include the physical parameters of glass microballoon, such as wall thickness and radius ration, but excluding the porosity and voids. Therefore, in this study additional parameters have been included, starting with the derivation from Turner's model, as shown in Equations (2) and (3) below:

$$\alpha = \frac{\alpha_m \beta_m K_m + \alpha_g \beta_g K_g}{\beta_m K_m + \beta_g K_g} \qquad (1)$$

$$(1.2)\mathrm{K} = \frac{E}{3(1-2\nu)} \qquad (3)$$

where K is a bulk moduli composite, considering K_m, K_g, modulus of elasticity for matrix resin and glass microballoon, while E is Young's modulus and ν is Poisson's ratio of glass microballoon, respectively.

3. RESULTS AND DISCUSSION

3.1 Dimension stability affected by physical properties

Figure 3.1 shows the typical result from a thermal dimension change with temperatures ranging between 20 ^{o}C – 75 ^{o}C. It reveals that the dimension change was steepest when it had different glass microballoon content in the syntactic foam but was still led by pure vinyl ester. It further showed that specimen 4 wt.% had a higher dimension change when compared with other specimens, which had a thicker wall thickness with higher porosities as well and the least voids content. The thin wall thickness contributed to the smaller dimension change belonging to the specimen with 10 wt.% as well as higher porosities content. These results contradicted previous findings reported by Shunmugasamy et al., (2012), who found that it related only to the wall thickness but they did not mention it in the context of porosity. This finding also agreed with their results that increasing the glass microballoon contents would likely increase the dimension stability in the syntactic foam as well.

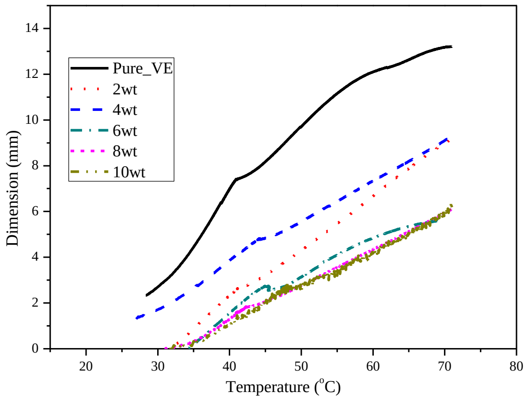

Figure 3.1 Typical result for thermal stability change with temperature

3.2 Coefficient of Thermal Expansion (CTE), α physical properties

From the experimental results, CTEs were analysed and compared to understand the effect of the physical parameters of syntactic foam on CTE. The CTE result for all specimens, including pure vinyl ester, is shown in Figure 3.2. It shows that the CTE of glass microballoon syntactic foam decreased when the glass microballoon in syntactic foam was increased. This graph reveals a 30 % - 70 % decrease in the CTE of syntactic foams compared to the neat resin result. The lowest CTE value was observed for 10 wt.% glass microballoon, which contained the lowest average wall thickness, as shown in Table 1.4. The reduction of CTE related to the physical properties of glass microballoons, such as wall thickness, radius ration, porosities and voids, which were interesting to discover for a more concrete understanding of how to obtain the quantitative parameters in this study. The percentage reduction of the CTE can be determined with a different (ratio) starting from pure vinyl ester and a specimen of 2 wt.%, Incorporation of filling with glass microballoon resulted in up to a 63 % reduction and it kept decreasing to 53 % for a temperature change from 30 ºC to 70 ºC.

The CTE values between 4 wt.% and 6 wt.%, and between 8 wt.% and 10 wt.% did not have much difference between them, whereas they were almost 5 % and 1 % if compared to each other, respectively. This gap could be contributed to the porosity and voids content occurring in the syntactic foam with a debris of glass microballoons. The thermal flow through these kinds of mechanisms will affect the CTE value in the syntactic foam and can be seen in the SEM photo in Chapter 5. The specimen with 2 wt.% had the highest CTE value, which also corresponded to the lower glass microballoon. This trend was also detected by Shunmugasamy et al., (2012) who also noted that the CTE value decreased when glass microballoon was added (with a 30 % - 60 % volume fraction) into the vinyl ester matrix resin.

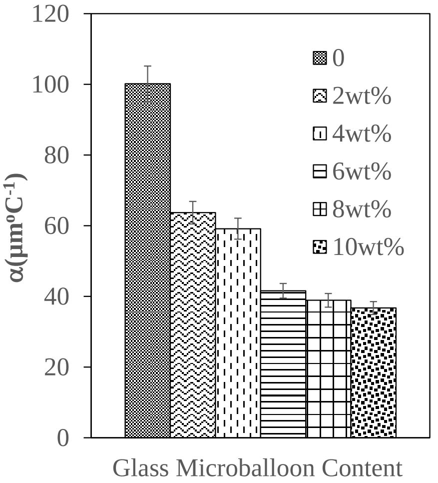

Figure 3.2 Experimental CTE measured values for neat resin and syntactic foam

4. SUMMARY

In the Thermomechanical Analysis (TMA) analysis, the linear dimension stability, also called coefficient of thermal expansion (CTE), decreased when the glass microballoon content increased. The modification of Turner's model was applied in this study for a comparison of CTE in three different temperatures (30 ºC, 50 ºC and 70 ºC) for syntactic foam. The modification included parametric study involvement into the effect of radius ration, porosity and voids content in syntactic foam. The porosity content contributed much more to the CTE value, especially gap of ratio, which was different from the matrix porosity.

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