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# TESTING CONTRACTION AND THERMAL EXPANSION COEFFICIENT OF CONSTRUCTION AND MOULDING POLYMER COMPOSITES

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## ABSTRACT

*The paper presents results of systematic tests of contraction and thermal expansion coefficients of materials based on polymer composites. The information on the above material properties is essential both at the design stage and during the use of finished products. Components for the samples were selected in such a way as to represent typical materials used for production of construction and moulding elements. The performed tests made it possible to monitor the analysed parameters at different stages of the technological process.*

**Keywords:** polymer composites, contraction, thermal expansion

## INTRODUCTION

Fibre reinforced polymer composite is the material with a relatively short history, as compared to traditional construction materials (wood, metals, concrete). Its development began at the turn of 1930s and 1940s [1]. This material is characterised by small volume density, relatively high mechanical strength and stiffness, high resistance to weather conditions and chemical agents, and high flexibility for geometry shaping. These properties make the composites very applicable in the shipbuilding industry [2,3]. They are used for production of various components and entire watercraft units, such as, for instance, the ferry Vision of The Fjords shown in Fig. 1.

Polymer composites are also appreciated and used in production of cars, airplanes, sports equipment, electrotechnical elements, etc. This material is also being more and more frequently used in civil engineering, in the form of construction profiles, reinforcement elements, and sandwich structures [4-7].

The structure of composites comprises the matrix, most frequently made of polyester, vinyl or epoxy resins, and reinforcement, where glass and carbon fabrics are most popular materials. As a result of resin/reinforcement combination, so-called laminate is created. This laminate can be additionally used as a component of sandwich structure, with polyurethane foam (PU), polyethylene terephthalate foam (PET), or another material, honeycomb for instance, used as core filler.

Samples of selected composites were tested within the framework of the project which aimed at creating a footbridge with sandwich structure (Fig. 2) using the vacuum infusion technology, which is typical for production of yacht hulls, among other applications [8-10]. The implemented project

[11-13] included a series of experimental, numerical and technological tests [14,15], which made it possible to monitor the entire process, from a preliminary concept to building a full-scale object. The finished footbridge was subjected to a series of static and dynamic tests [15,18] and technical monitoring [25] based on earlier gained experience [19-24].

*Fig. 1. Passenger ferry Vision of The Fjords*

*Fig. 2. Footbridge built on the Gdansk University of Technology campus territory within the framework of the project FOBRIDGE*

An essential aspect in designing and use of composite structures is analysing the effect of contraction and temperature on the finished product. Thermosetting resins used for production of composites experience chemical contraction during hardening and heat soaking processes. Methods to determine this parameter are divided into two groups: volumetric and non-volumetric. Representative measurement techniques for both groups are discussed in [26]. Numerous publications can be found in the literature which present results for the same resin [27-29]. On the other hand, determining contraction in finished composite elements is much more rarely analysed. The process itself is very complex, as it depends on percentage and direction of reinforcement. This phenomenon was analysed in [30], among other publications. The problem of contraction appearance at the production stage can affect both the dimensions and shape of the finished product, and the residual stresses activated during the hardening and heat soaking processes [31,32]. A similar situation is when assessing the linear thermal expansion coefficient for laminates and sandwich structures, as this parameter also depends of percentage and direction of reinforcement. Its variability can be illustrated by the range of values 1,62 ÷ 2,7 m/m/$^{o}$C given in the ASME (American Society of Mechanical Engineers) standard B31.3.

This paper analyses the assessment of contraction parameters and thermal expansion coefficients for selected resins, reinforcements, and cores used in sandwich structures. The tests were performed for construction materials, in versions of pure laminate and sandwich structure, and for moulding materials.

## MATERIALS, PREPARING SAMPLES

The tests were performed with materials which can be used for production of construction components of finished products, and production of moulds needed in the vacuum infusion technology. The following components were used for preparing samples:

a) glass reinforcements: glass fabrics E, bi-directional, stitched – BAT 800 [0/90], GBX 800 [45/-45], and glass mats E – CSM 300, CSM 450,
b) sandwich materials: construction foam PU of 50 mm in thickness, and Lantor Coremat mat of 3 mm in thickness (used in production of moulds),
c) construction resins: vinyl ester resin BÜFA – Firestop S 440, and vinyl ester resin POLIMAL – VE-2 MM,
d) moulding resins: vinyl ester resin POLYLITE – 410-900, and polyester resin Norester – RM 2000.

Using the above materials, five plates of dimensions of 200×200 mm were prepared. All samples were made using manual laminating technology (Fig. 3). Detailed specifications of plates are collated in Table 1.

*Fig. 3. Making test samples*

*Tab. 1. Specifications of samples*

| Sample label | Resin | Sequence of layers |
|---|---|---|
| P1 | BÜFA - Firestop S 440 construction resin | 1 × CSM 300<br>1 × BAT 800<br>2 × GBX 800<br>1 × BAT 800<br>**PU foam**<br>1 × BAT 800<br>2 × GBX 800<br>1 × BAT 800<br>1 × CSM 450 |
| P2 | BÜFA - Firestop S 440 construction resin | 1 × CSM 300<br>1 × BAT 800<br>2 × GBX 800<br>1 × BAT 800 |

| Sample label | Resin | Sequence of layers |
|---|---|---|
| P3 | POLIMAL - VE-2 MM construction resin | 1 × CSM 300<br>1 × BAT 800<br>2 × GBX 800<br>1 × BAT 800 |
| P4 | POLYLITE - 410-900 moulding resin | 1 × CSM 300<br>3 × CSM 450<br>**Coremat**<br>3 × CSM 450 |
| P5 | Norester - RM 2000 moulding resin | 1 × CSM 300<br>3 × CSM 450<br>**Coremat**<br>3 × CSM 450 |

## MEASUREMENT TECHNIQUE

To enable measurements of contraction and thermal expansion coefficient, four benchmarks were placed on each sample, thus creating two deformation measurement bases of 100 mm in length and perpendicular to each other. The benchmarks were embedded into the plate before resin gelation (Fig. 4).

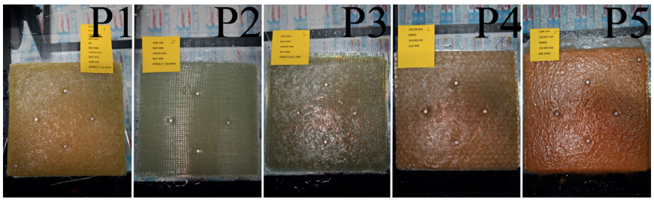


*Fig. 4. Benchmarks placed on samples*

The length changes were measured using an electronic extensometer Mitutoyo with resolution of up to 0,001 mm (Fig. 5). Additionally, a pyrometer (surface infrared thermometer) TQC model TE1005 was used in tests which aimed at determining the linear thermal expansion coefficient. The measurement range of this pyrometer was –50°C ÷ 750°C and the resolution was 0,1°C.

*Fig. 5. Extensometer used for length change measurement*

## CONTRACTION MEASUREMENT AFTER SAMPLE PREPARATION

Firstly, the sample contraction was measured which appeared as a result of resin gelation. During the tests, the samples remained in the room temperature. The deformation was measured once a day during first four days after plate preparation. During this time interval the contraction stabilised. To check whether the samples do not undergo further contraction in a longer time interval, the contraction was additionally measured after two weeks and after one month. The results are shown in Fig. 6. For each plate, permanent deformation directly after preparation, $\varepsilon_{perm,0}$, was determined. The final value was calculated as the arithmetic mean from two measurements. The results are collated in Table 2.

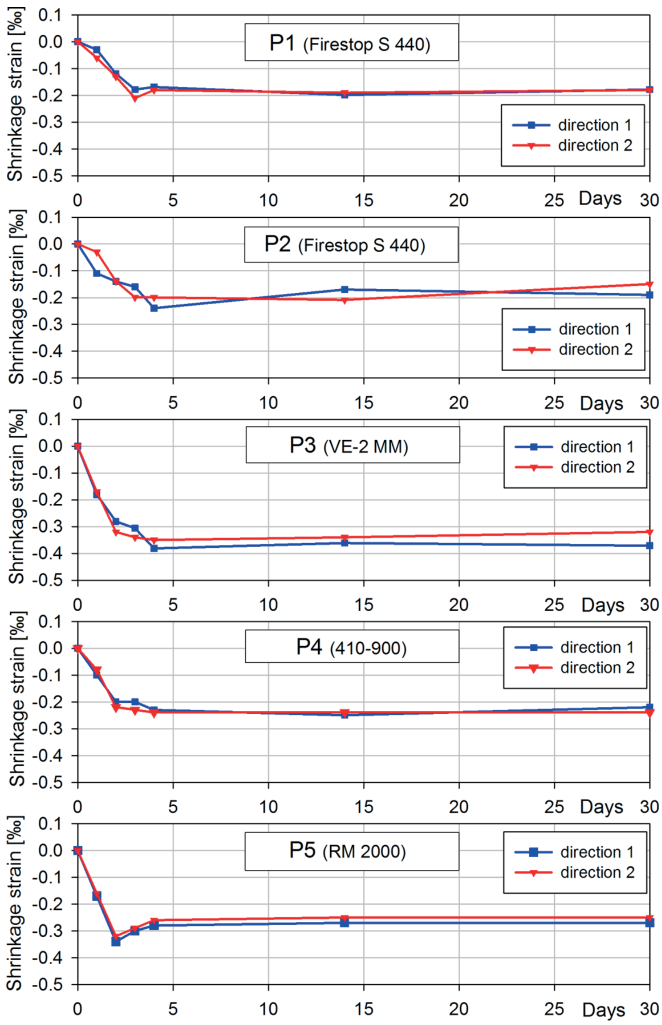


*Fig. 6. Measurement of contraction deformations after preparation of samples P1-P5*

*Tab. 2. Permanent contraction deformations directly after sample preparation*

| Sample label | Resin | $\varepsilon_{perm,0}$ [‰] |
|---|---|---|
| P1 | Firestop S 440 | -0,18 |
| P2 | Firestop S 440 | -0,18 |
| P3 | POLIMAL - VE-2 MM | -0,35 |
| P4 | POLYLITE - 410-900 | -0,24 |
| P5 | Norester - RM 2000 | -0,26 |

Contraction and linear thermal expansion coefficient measurements during heat soaking

The next test step was measuring the contraction and linear thermal expansion coefficient of the samples during and after their heat soaking. The procedure of 10-hour heat soaking in the temperature of 90°C was divided into three phases. The initial sample cooling was done as early as after 30 minutes of soaking, the second – after basic soaking, i.e. after 9,5 hours, and the third – after process completion, i.e. after 10 hours.

## MEASUREMENT AFTER FIRST HEAT SOAKING PHASE

The samples were placed inside the thermal chamber for 30 min. Then, after removing them from the chamber, the deformation and surface temperature of the samples were simultaneously measured during sample cooling. The results are shown in Fig. 7. For each plate, permanent deformation after first heating, $\varepsilon_{perm,1}$, was determined. Its final value was calculated as the arithmetic mean from two measurements. Another parameter determined for each plate at this stage was the linear thermal expansion coefficient after first heating, $\alpha_1$. Here, the final value was also calculated as the arithmetic mean from two measurements, for which the least squares regression line was also determined. The results are collated in Table 3.

*Tab. 3. Permanent contraction deformations and linear thermal expansion coefficients after first heat soaking phase*

| Sample label | Resin | $\varepsilon_{perm,1}$ [‰] | $a_1$ [m/m/°C] |
|---|---|---|---|
| P1 | Firestop S 440 | -0,80 | 2,38e-5 |
| P2 | Firestop S 440 | -0,81 | 1,92e-5 |
| P3 | POLIMAL - VE-2 MM | -1,19 | 2,62e-5 |
| P4 | POLYLITE - 410-900 | -0,78 | 2,58e-5 |
| P5 | Norester - RM 2000 | -0,22 | 1,33e-5 |

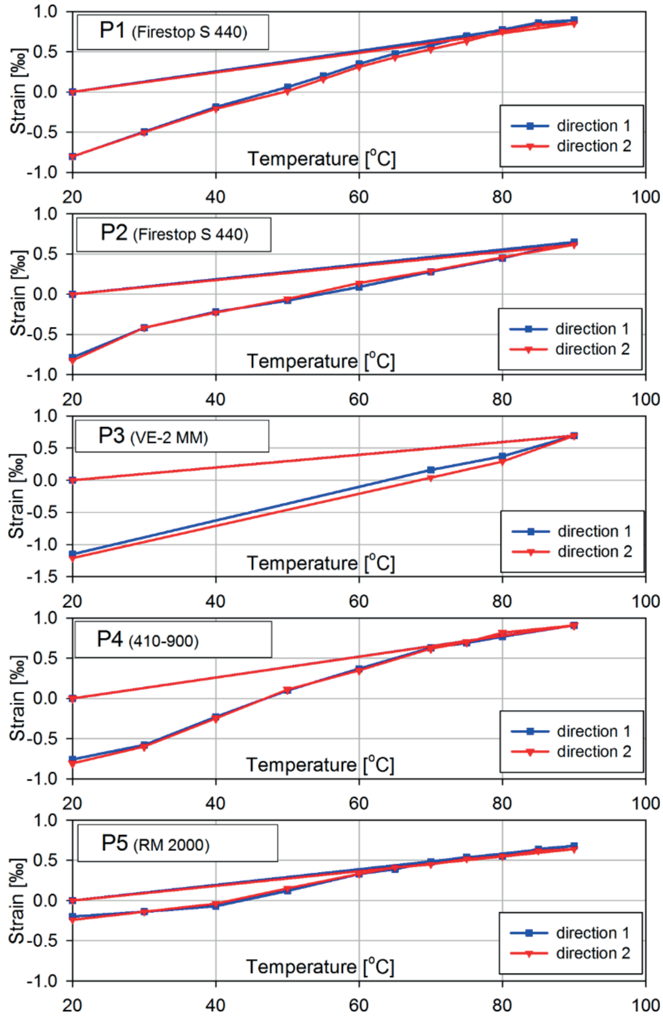


*Fig. 7. Results of deformation measurements during cooling of samples P1-P5 after first heat soaking phase*

## MEASUREMENT AFTER SECOND HEAT SOAKING PHASE

In the second heat soaking phase, the samples underwent basic soaking which lasted 9 hours. After removing them from the thermal chamber, the deformation and surface temperature of the samples were simultaneously measured during sample cooling. For each plate, permanent deformation after basic 9-hour heating, $\varepsilon_{perm,2}$ and the linear thermal expansion coefficient $\alpha_2$ were determined. The final values were calculated in the identical way as in the previous measurement. The results are shown in Fig. 8 and Table 4.

*Tab. 4. Permanent contraction deformations and linear thermal expansion coefficients after second heat soaking phase*

| Sample label | Resin | $e_{perm,2}$ [‰] | $a_2$ [m/m/°C] |
|---|---|---|---|
| P1 | Firestop S 440 | -0,01 | 2,42e-5 |
| P2 | Firestop S 440 | -0,09 | 1,81e-5 |
| P3 | POLIMAL - VE-2 MM | -0,07 | 2,50e-5 |
| P4 | POLYLITE - 410-900 | -0,06 | 2,79e-5 |
| P5 | Norester - RM 2000 | -0,25 | 1,64e-5 |

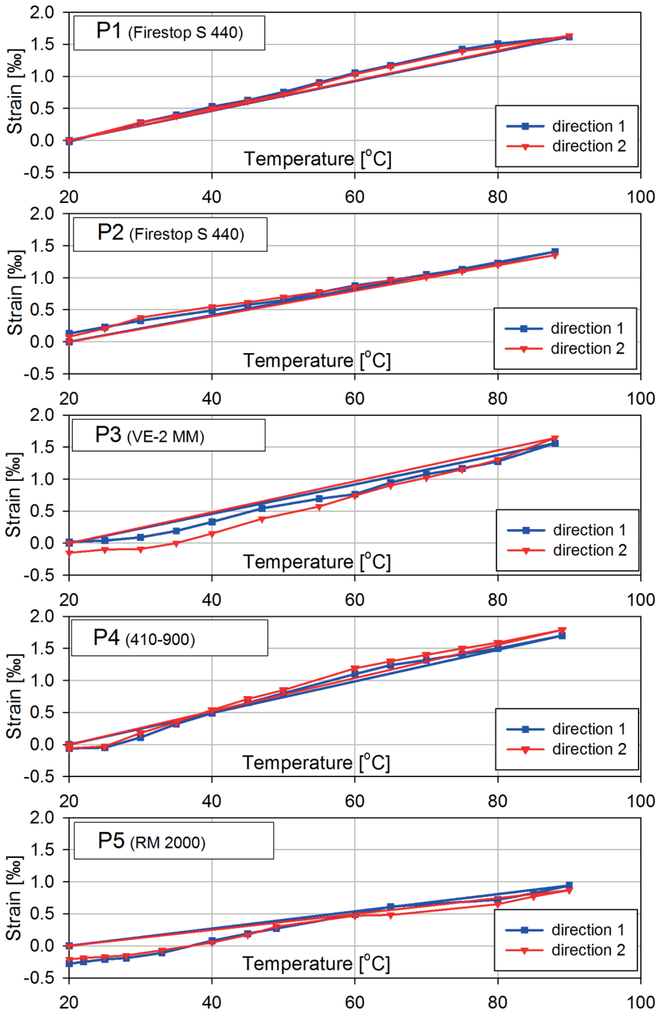


*Fig. 8. Results of deformation measurements during cooling of samples P1-P5 after second heat soaking phase*

## MEASUREMENT AFTER THIRD HEAT SOAKING PHASE

The final test step was measuring sample contraction during cooling after completion of the heat soaking process. For each plate, permanent deformation formed during the last 30-minute soaking stage, $\varepsilon_{perm,3}$, and the linear thermal expansion coefficient $\alpha_3$ were determined. The final values were calculated in the identical way as in the previous measurements. The results are shown in Fig. 9 and Table 5.

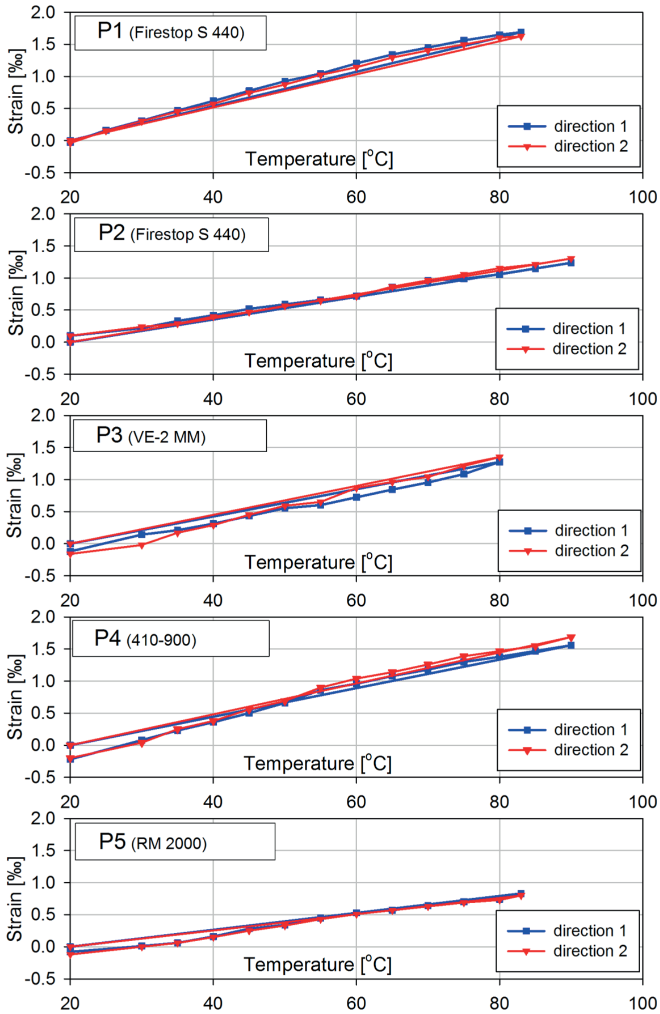


*Fig. 9. Results of deformation measurements during cooling of samples P1-P5 after third heat soaking phase*

*Tab. 5. Permanent contraction deformations and linear thermal expansion coefficients after third heat soaking phase*

| Sample label | Resin | $\varepsilon_{perm,3}$ [‰] | $\alpha_3$ [m/m/°C] |
|---|---|---|---|
| P1 | Firestop S 440 | -0,03 | 2,60e-5 |
| P2 | Firestop S 440 | 0,03 | 1,75e-5 |
| P3 | POLIMAL - VE-2 MM | -0,14 | 2,43e-5 |
| P4 | POLYLITE - 410-900 | -0,21 | 2,69e-5 |
| P5 | Noreste r - RM 2000 | -0,10 | 1,50e-5 |

## CONCLUSIONS

The values of total permanent contraction deformation $\varepsilon_{perm}$ created during the hardening and heat soaking processes are collated in Table 6. It can be noticed that in the case of construction resins (samples P1, P2, P3) the largest total contraction deformation was recorded for sample P3 (Resin POLIMAL - VE-2 MM), while for moulding resins (samples P4, P5) – for sample P4 (Resin POLYLITE - 410-900). After analysing Tables 3-5, a conclusion can be made that the largest increase of contraction deformation takes place as early as after the first, preliminary heat soaking phase. This tendency was observed for all tested materials. Comparing results for samples P1 and P2 leads to the conclusion that, in both the independent form and as sandwich structure component, the laminate has very similar contraction deformation level at each analysis stage.

*Tab. 6. Permanent contraction deformations directly after sample preparation*

| Sample label | Resin | $\varepsilon_{perm}$ [‰] |
|---|---|---|
| P1 | Firestop S 440 | -1,02 |
| P2 | Firestop S 440 | -1,05 |
| P3 | POLIMAL - VE-2 MM | -1,75 |
| P4 | POLYLITE - 410-900 | -1,29 |
| P5 | Norester - RM 2000 | -0,83 |

The mean values of linear thermal expansion coefficient α from the results obtained at different test stages are shown in Table 7. Like for the contraction measurement, higher values (i.e. less favourable from the point of view of construction/mould performance) were recorded for samples P3 (Resin POLIMAL - VE-2 MM) and P4 (Resin POLYLITE - 410-900). When analysing the results obtained for samples P1 and P2 we can conclude that incorporating the laminate into the sandwich structure increases the linear thermal expansion coefficient of the entire structure.

*Tab. 7. Mean values of linear thermal expansion coefficients*

| Sample label | Resin | $\alpha$ [m/m/°C] |
|---|---|---|
| P1 | Firestop S 440 | 2,47E-05 |
| P2 | Firestop S 440 | 1,83E-05 |
| P3 | POLIMAL - VE-2 MM | 2,52E-05 |
| P4 | POLYLITE - 410-900 | 2,69E-05 |
| P5 | Norester - RM 2000 | 1,49E-05 |

What is also noteworthy is highest values of linear thermal expansion coefficients for all tested composites, as compared to traditional materials, such as metals, for instance. The above characteristic and the contraction phenomenon taking place in the composite material production process should be taken into account at the design and technological test stages. In cases of such large-scale elements as yacht hulls or building structures, the compatibility of real dimensions with design assumptions can be verified using, for instance, advanced photogrammetry techniques [33].

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