Data Article

Data supporting micromechanical models for the estimation of Young’s modulus and coefficient of thermal expansion of titanate nanotube/Y_2W_3O_{12}/HDPE ternary composites

Patricia I. Pontón a, Katia Yamada b, Marco V. Guaman c, Michel B. Johnson d, Mary Anne White d, e, Bojan A. Marinkovic b, f, *

a New Materials Laboratory, Department of Materials, Escuela Politécnica Nacional, 170525, Quito, Ecuador
b Centro Universitário de Volta Redonda — UNIFOA, Av. Paulo Erlei Alves Abrantes 1325, Volta Redonda, RJ, Brazil
c Department of Mechanical Engineering, Escuela Politécnica Nacional, 170525, Quito, Ecuador
d Clean Technologies Research Institute, Dalhousie University, Halifax, Nova Scotia, B3H 4R2, Canada
e Department of Chemistry, Dalhousie University, Halifax, Nova Scotia, B3H 4R2, Canada
f Department of Chemical and Materials Engineering, Pontifical Catholic University of Rio de Janeiro, 22451-900, Rio de Janeiro, RJ, Brazil

A R T I C L E   I N F O

Article history:
Received 27 April 2019
Received in revised form 10 June 2019
Accepted 5 July 2019
Available online 15 July 2019

Keywords:
Elastic constants
Coefficient of thermal expansion
Micromechanics
Thermomiotics
Titanate nanostucture
Three-phase composites

A B S T R A C T

This article presents several micromechanical models to predict the Young’s modulus and the coefficient of thermal expansion of titanate nanotube/Y_2W_3O_{12}/HDPE composites. The equations and assumptions of the selected micromechanical models are described in detail for this ternary system. Data of the elastic constants, coefficient of thermal expansion of composite components and other associated parameters, obtained either by literature survey or processing of literature information, are compiled in this work. For further interpretation of the data presented in this article, please see our research article entitled “The effect of titanate nanotube/Y_2W_3O_{12} hybrid fillers on mechanical and thermal properties of HDPE-based composites” (Pontón et al., 2019).

© 2019 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

* Corresponding author. Department of Chemical and Materials Engineering, Pontifical Catholic University of Rio de Janeiro, 22451-900, Rio de Janeiro, RJ, Brazil.
E-mail address: bojan@puc-rio.br (B.A. Marinkovic).

https://doi.org/10.1016/j.dib.2019.104247
2352-3409/© 2019 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).
1. Data

The data presented in this article include a collection of four micromechanical models to predict the stiffness of polymer composites reinforced with particulate hybrid fillers comprising titanate nanotubes (TTNT) and yttrium tungstate (Y2W3O12), which is a thermomiotic-like filler. These models are: the rule of mixtures (ROM), modified rule of mixtures (MROM), Halpin-Tsai and Hashin-Shtrikman. The equations of these models and the corresponding assumptions (see footnotes) are summarized in Table 1, along with the data of elastic constants and specific parameters for each composite phase. Table 2 presents a compendium of the micromechanical models chosen for the estimation of the coefficient of thermal expansion (CTE) of TTNT/Y2W3O12/HDPE composites, such as the rule of mixtures (ROM), Turner's and Schapery's models. The assumptions of these models (see footnotes) are also described, as well as, the bulk modulus and CTE for each composite phase.

2. Experimental design, materials, and methods

The data of micromechanical models presented in Tables 1 and 2 were selected from the literature to describe the TTNT/Y2W3O12/HDPE ternary system, depicted in Scheme 1. These ternary composites can be composed by different TTNT/Y2W3O12 mass ratios: 1:2, 1:1 and 2:1 and prepared using three approaches whether the hybrid filler and the matrix are modified or not: i) pristine hybrid fillers < composites denoted as C1:2, C1:1 and C2:1>, ii) hybrid fillers modified with...
### Table 1
Models for prediction of Young’s modulus of HDPE-based composites reinforced with TTNT/Y₂WO₄ hybrid filler and data associated with the elastic constants and specific parameters for each composite phase.

| Model                        | Prediction                                                                 | Eq. | Variables and parameters                                                                                     |
|------------------------------|----------------------------------------------------------------------------|-----|-------------------------------------------------------------------------------------------------------------|
| Rule of mixture (ROM)        | \( E_c = E_{f_1}f_{f_1} + E_{f_2}f_{f_2} + E_m(1 - f_{f_1} - f_{f_2}) \) | (1) | \( E_c = \text{Young's modulus of the composite} \)
|                              | \( E_{f_1} = \frac{9K_{f_1}G_{f_1}}{3K_{f_1} + G_{f_1}} \)                |     | \( E_{f_2} = \text{Young's modulus of HDPE} = 0.824 \text{ GPa} \) [1] \( E_{f_2} = \text{Young's modulus of TTNT} = 260 \text{ GPa} \) [2] \( E_m = \text{Young's modulus of Y}_2\text{W}_3\text{O}_{12}, \text{calculated from Eq. 2.} \)
|                              | \( K_{f_2} = \text{Bulk modulus of Y}_2\text{W}_3\text{O}_{12} = 25 \text{ GPa} \) [3] |     | \( G_{f_2} = \text{Shear modulus of Y}_2\text{W}_3\text{O}_{12} = 12 \text{ GPa} \) [4] \( f_{f_1} = \text{volume fraction of TTNT} \)
|                              | \( f_{f_2} = \text{volume fraction of Y}_2\text{W}_3\text{O}_{12} \)              |     | \( \beta_1 = \text{strengthening factor} \text{ (also called as modulus efficiency factor), ranging between 0 and 1} \) [6]. \( \beta_1 = \text{strengthening factor of TTNT} \) [7,8] \( \beta_2 = \text{strengthening factor of Y}_2\text{W}_3\text{O}_{12} \) \( \beta = \text{strengthening factor of Y}_2\text{W}_3\text{O}_{12} \text{~ 0.2} \) [9,10] |
| Modified rule of mixture (MROM) | \( E_c = \beta_1E_{f_1}f_{f_1} + \beta_2E_{f_2}f_{f_2} + E_m(1 - f_{f_1} - f_{f_2}) \) | (3) | \( Em_1 = \text{Young's modulus of HDPE/Y}_2\text{W}_3\text{O}_{12} \text{ composite, which is considered as a new matrix, calculated with Eq. 5.} \)
|                              | \( \eta_{f_1} = \frac{E_{f_1}}{E_m} - 1 \)                              |     | \( I_{f_1} = \text{length of TTNT} \approx 100 \text{ nm} \) [11] \( \eta_{f_2} = \text{shape parameter of TTNT} \approx 20, \text{calculated with Eq. 7.} \)
|                              | \( \zeta_{f_1} = 2\left(\frac{l_{f_1}}{d_{f_1}}\right) \)               | (7) | \( z_{f_1} = \text{shape parameter of TTNT} \approx 2, \text{as the first approximation for spherical particulate fillers.} \)
|                              | \( \eta_{f_2} = \frac{E_{f_2}}{E_m} + \frac{z_{f_2}}{E_m} \)             | (8) |  |
|                              | \( \eta_T = \frac{E_{f_1}}{E_m} + 2 \)                                  | (9) |  |

| Model                        | Prediction                                                                 | Eq. | Variables and parameters                                                                                     |
|------------------------------|----------------------------------------------------------------------------|-----|-------------------------------------------------------------------------------------------------------------|
| Halpin-Tsai model            | \( E_c = E_{m_1}\left[\frac{3}{8}\left(1 + \zeta_{f_1} \eta_{f_1} \phi_{f_1}\right) + \frac{5}{8}\left(1 + 2\eta_{f_1} \phi_{f_1}\right)\right]\) | (4) | \( Em_1 = \text{Young's modulus of Y}_2\text{W}_3\text{O}_{12} \approx 0.1 \)
|                              | \( E_{m_1} = E_m(1 + \zeta_{f_1} \eta_{f_1} \phi_{f_1}) \)              |     | \( Em_1 = \text{Young's modulus of HDPE/Y}_2\text{W}_3\text{O}_{12} \) \( d_{f_1} = \text{diameter of TTNT} \approx 10 \text{ nm} \) [11] |
|                              | \( \eta_{f_1} = \frac{E_{f_1}}{E_{m_1}} - 1 \)                          |     |  |
|                              | \( \zeta_{f_1} = 2\left(\frac{l_{f_1}}{d_{f_1}}\right) \)               | (7) |  |
|                              | \( \eta_{f_2} = \frac{E_{f_2}}{E_{m_1}} + \frac{z_{f_2}}{E_{m_1}} \)   | (8) |  |
|                              | \( \eta_T = \frac{E_{f_1}}{E_{m_1}} + 2 \)                             | (9) |  |
Table 1 (continued)

| Model                  | Prediction                                                                 | Eq.               | Variables and parameters                                                                 |
|------------------------|---------------------------------------------------------------------------|-------------------|----------------------------------------------------------------------------------------|
| Hashin-Shtrikman model | \( E'_c = \frac{9K_c^2C_c}{3K_c^2 + C_c} \)                               | (10)              | \( E'_c, E''_c \) = lower and upper bounds of Young’s modulus of composite              |
|                        | \( E''_c = \frac{9K_cC_c^2}{3K_c^2 + C_c} \)                              | (11)              | \( K'_c, K''_c \) = lower and upper bounds of bulk modulus of                          |
|                        |                                                                          |                   | composite calculated from Eqs. 12 and 13.                                              |
|                        |                                                                          |                   | \( \phi_{hyb} \) = volume fraction of the hybrid filler calculated with Eq. 14.        |
|                        |                                                                          |                   | \( K_{hyb} \) = bulk modulus of the hybrid filler                                      |
|                        |                                                                          |                   | computed with Eq. 15.                                                                  |
|                        |                                                                          |                   | \( K'_f \) = bulk modulus of \( \gamma_2W_3O_{12} \approx 25 \) GPa [3]               |
|                        |                                                                          |                   | \( \phi'^{f}{_f} \) = volume fraction of the hybrid filler                            |
|                        |                                                                          |                   | computed with Eq. 16.                                                                  |
|                        |                                                                          |                   | \( K_{hyb} \) = shear modulus of the hybrid filler                                       |
|                        |                                                                          |                   | calculated with Eq. 22.                                                               |

where,

\[
K'_c = K_m + \frac{\phi_{hyb}}{K_{hyb} - K_m + \frac{3(1 - \phi_{hyb})}{K_{hyb}}} + \frac{1 - \phi_{hyb}}{K_{hyb} + \frac{3\phi_{hyb}}{K_{hyb} + 4G_{hyb}}}
\]

(12)

\[
K''_c = K_{hyb} + \frac{1}{K_{hyb} + \frac{1 - \phi_{hyb}}{K_{hyb} + \frac{3\phi_{hyb}}{K_{hyb} + 4G_{hyb}}}}
\]

(13)

\[
\phi_{hyb} = \phi^{f}_{f} + \phi^{l}_{l}
\]

(14)

\[
K_{hyb} = \phi^{f}_{f}K_{f} + \phi^{l}_{l}K_{l}
\]

(15)

\[
\phi^{f}_{f} = \frac{\phi^{f}_{f}}{\phi^{f}_{f} + \phi^{l}_{l}}
\]

(16)

\[
\phi^{l}_{l} = \frac{\phi^{l}_{l}}{\phi^{f}_{f} + \phi^{l}_{l}}
\]

(17)

\[
K_{m} = \frac{E_{m}G_{m}}{3(3G_{m} - E_{m})}
\]

(18)

\[
G_{m} \approx \frac{3}{8} E_{m}
\]

(19)

\[
G'_{c} = G_{m} + \phi_{hyb} \left[ 1 - \frac{6(1 - \phi_{hyb})(K_{m} + 2G_{m})}{5G_{m}(3K_{m} + 4G_{m})} \right]^{-1}
\]

(20)

\[
G''_{c} = G_{hyb} + (1 - \phi) \left[ 1 - \frac{6\phi(K_{hyb} + 2G_{hyb})}{5G_{hyb}(3K_{hyb} + 4G_{hyb})} \right]^{-1}
\]

(21)

\[
G_{hyb} = \phi^{f}_{f}G_{f} + \phi^{l}_{l}G_{l}
\]

(22)

\[a\] Value obtained from tensile test [1].

\[b\] Young’s modulus of hydrothermally synthesized TTNT are not reported in the literature. Therefore, corresponding value of hydrothermally synthesized titanate nanoribbons [2] was assumed, which is similar to Young’s modulus of TiO2 \( (E_{TiO_2} = 282.76 \) GPa) [12,13].

\[c\] \( G_c \) is unavailable in the literature. Hence, \( G_{\gamma_2W_3O_{12}} \) was used [14], since bulk moduli of both materials are similar \( (K_{\gamma_2W_3O_{12}} = 12 \) GPa). If the product between \( \beta \) and \( E_{f} \) is termed as effective Young’s modulus of filler \( (E_{eff}) \).

\[e\] Since the length of TTNT is much smaller than the specimen thickness, it is expected that TTNT are randomly oriented in 3D [7]. Thus, \( \beta_{1} \) is assumed as 0.2, value used in the literature as a first approximation for 3D randomly oriented carbon nanotubes [7] and particulate fillers, such as TiO2 [8].
Micromechanical models for prediction of CTE of HDPE-based composites reinforced with TTNT/Y2W3O12 hybrid 

Table 2

| Model                      | Prediction                                      | Eq. | Variables and parameters |
|----------------------------|-------------------------------------------------|-----|--------------------------|
| Rule of mixture (ROM)      | $a_c = a'_f \phi_f + a'_l \phi_l + a_m(1 - \phi_f - \phi_l)$ | (23) | $a_c$ = CTE of the composite  
|$a_m$ = CTE of matrix (HDPE) = $188 \times 10^{-6}$ °C$^{-1}$ |
| Turner’s model [22]        | $a_c = \frac{\phi_f K_f a'_f + \phi_l K_l a'_l + a_m(1 - \phi_f - \phi_l)K_m}{\phi_f K_f' + \phi_l K_l' + (1 - \phi_f - \phi_l)K_m}$ | (24) | $\phi_f$, $\phi_l$ = volume fraction of TTNT, Y2W3O12, respectively |
| Schapery’s [23] model e     | $a'_c = \alpha_m + \frac{K_{hyb} (K_m - K'_c)(a_{hyb} - \alpha_m)}{K'_c (K_m - K_{hyb})}$ | (25) | $a_{hyb}$ = volume fraction of TTNT, Y2W3O12, respectively |
|                            | $a'_c = \alpha_m + \frac{K_{hyb} (K_m - K'_c)(a_{hyb} - \alpha_m)}{K'_c (K_m - K_{hyb})}$ | (26) | $\alpha_m$, $\alpha_c$ = lower and upper bounds of CTE of the composite reinforced with the hybrid filler |
|                            | where, $a_{hyb} = \phi'_f a'_f + \phi'_l a'_l$ | (27) | $K_{hyb}$ = bulk modulus of the hybrid filler computed with Eq. 15. |

Notes:

a Value measured by dilatometry in the temperature range of 30–70 °C and during the second heating cycle [1].
b CTE of TTNT is unavailable in the literature. Therefore, corresponding value of TiO2 was assumed.
c Bulk modulus of hydrothermally synthesized TTNT is not reported in the literature. Hence, corresponding value of analogous anatase TiO2 nanotubes, synthesized by a similar alkaline hydrothermal method followed by an acid washing and annealing treatment, was used [18].
d The bulk modulus of HDPE was calculated using the experimental Young’s modulus of HDPE, assuming that this remains unchanged after heating samples up to 70 °C, as a first approximation.
e Since $K'_f$ and $K'_l$ for ternary phase composites are calculated in the literature using Eq. 12 and 13 [16,17], and Schapery’s model takes into account these two values, it is reasonable to compute $a'_c$ and $a'_c$ defining $K_{hyb}$ and $a_{hyb}$ by the rule of mixture (see Eq. 15 and Eq. 27, respectively).
Cetyltrimethylammonium bromide (CTAB) composites designated as C2:1-CTAB and iii) HDPE modified with polyethylene-grafted maleic anhydride (PE-g-MA) as compatibilizer composites called as C2:1-PE-g-MA.

The computation of the volume fractions of TTNT and Y2W3O12 ($\phi_1$ and $\phi_2$, respectively) for the application of these models is presented in reference [1]. The mechanical and thermal properties of TTNT are assumed to be equal to those values of similar titania-based materials, as a first approximation, since they are not reported in the literature.

For the application of MROM for the TTNT/Y2W3O12/HDPE ternary system (see Eq. 3), the strengthening factor of Y2W3O12 ($\beta_2$) was calculated from the experimental Young’s moduli of HDPE/Y2W3O12 composites using data reported by Pontón et al. [14]. The MROM for these binary composites can be expressed as:

$$E_{c2} = \beta_2 E_f \phi_2 + E_m \left(1 - \phi_2\right)$$  \hspace{1cm} (28)

$$E_{c2} = \left(\beta_2 E_f - E_m\right)\phi_2 + E_m$$  \hspace{1cm} (29)
Therefore, $b_2$ can be calculated from the slope of $E_c$ as a function of $f_2$. The linear fitting of experimental Young’s moduli of HDPE/$Y_2W_3O_{12}$ composites is presented in Fig. 1.

The volume fractions of TTNT and $Y_2W_3O_{12}$ within the hybrid filler, $f_{1}$ and $f_{2}$, respectively, are presented in Table 3. These values were calculated with Eq. 16 and Eq. 17 from the volume fractions of both fillers ($\phi_{f_1}$, $\phi_{f_2}$) inside the whole composite, and they are required for application of both Hashin-Shtrikman and Schapery’s models.

$$E_c = 2390.15\phi_{f_2} + 827.4 \quad (R^2 = 0.995) \quad (30)$$

$$\beta_{f_2} E_{f_2} - E_m = 2390.15 \quad (31)$$

$$\therefore \beta_{f_2} = 0.1$$
There is a lack of information in the literature related to the application of Schapery’s model to predict the CTE of polymer composites reinforced with a hybrid filler. The present approach of application of Schapery’s model equation for binary composites to ternary ones (see Eq. 25 and Eq. 26) was based on the assumptions previously used in Hashin-Shtrikman model (see footnote “i” in Table 1), since both models depend on $K^i$ and $K^u$.

All micromechanical models presented in this article assumes perfect interfaces and homogenous dispersion of hybrid fillers. Experimental deviations from these models can be observed as a result of different dispersion states of fillers inside the matrix and/or the presence of the interfacial groups at hybrid filler-matrix interfaces.

Acknowledgments

P. I. P. and M. V. G. acknowledge support from Escuela Politécnica Nacional (project PII-DMT-02-2018). B.A.M. is grateful to CNPq (National Council for Scientific and Technological Development) for a Research Productivity Grant. M.A.W. acknowledges support from NSERC Canada and the Clean Technologies Research Institute at Dalhousie University.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] P.I. Pontón, K. Yamada, M.V. Guamán, M.B. Johnson, M.A. White, O. Pandoli, A.M.L.M. Costa, B.A. Marinkovic, The effect of titanate nanotube/Y2WO4 hybrid fillers on mechanical and thermal properties of HDPE-based composites, Mater. Today Commun. 18 (2019) 124–135, https://doi.org/10.1016/j.mtcomm.2018.11.014.
[2] M. Humar, D. Arccon, P. Úmek, M. Škarabot, I. Musesić, G. Bregar, Mechanical properties of titania-derived nanoribbons, Nanotechnology 17 (2006) 3869–3872, https://doi.org/10.1088/0957-4484/17/15/043.
[3] S. Karmakar, S.K. Deb, A.K. Tyagi, S.M. Sharma, Pressure-induced amorphization in Y2(WO4)2: in situ X-ray diffraction and Raman studies, J. Solid State Chem. 177 (2004) 4087–4092, https://doi.org/10.1016/j.jssc.2004.08.020.
[4] C.P. Romao, K.J. Miller, M.B. Johnson, J.W. Zwanziger, B.A. Marinkovic, M.A. White, Thermal, vibrational, and thermoelastic properties of Y2Mo3O12 and their relations to negative thermal expansion, Phys. Rev. B. 90 (2014) 024305, https://doi.org/10.1103/PhysRevB.90.024305.
[5] S. Fu, G. Xu, Y. Mai, On the elastic modulus of hybrid particle/short-fiber/polymer composites, Compos. B Eng. 33 (2002) 291–299, https://doi.org/10.1016/S1359-8368(02)00013-6.
[6] F.X. Espinach, F. Julian, N. Verdaguer, L. Torres, M.A. Pelach, F. Vilaseca, P. Mutje, Analysis of tensile and flexural modulus in hemp strands/polypropylene composites, Composites B 47 (2013) 339–343, https://doi.org/10.1016/j.compositesb.2012.11.021.
[7] U.A. Khashaba, Improvement of toughness and shear properties of multiwalled carbon nanotubes/epoxy composites, Polym. Compos. 39 (2018) 815–825, https://doi.org/10.1002/pc.24003.
[8] A.M. Díez-Pascual, A.L. Díez-Vicente, Development of linseed oil-TiO2 green composites as antimicrobial coatings, J. Mater. Chem. B 21 (2015) 4458–4471, https://doi.org/10.1039/C5TB00209E.
[9] C. Halpin, J.L. Kardos, The Halpin-Tsai equations: a review, Polym. Eng. Sci. 16 (1976) 344–352, https://doi.org/10.1002/pen.13570160114.
[10] C. Xiao, Y. Tan, X. Yang, T. Xu, L. Wang, Z. Qi, Mechanical properties and strengthening mechanism of epoxy resin reinforced with nano-SiO2 particles and multi-walled carbon nanotubes, Chem. Phys. Lett. 695 (2018) 34–43, https://doi.org/10.1016/j.cplett.2018.01.060.
[11] E. Morgado, M.A.S. De Abreu, O.R.C. Pravia, B.A. Marinkovic, A study on the structure and thermal stability of titanate nanotubes as a function of sodium content, Solid State Sci. 8 (2006) 888–900, https://doi.org/10.1016/j.solidstatesciences.2006.02.029.
[12] E.J.F. Shackleford, W. Alexander, Mechanical properties of materials, in: E.J.F. Shackleford, W. Alexander (Eds.), CRC Mater. Sci. Eng. Handbook, third ed., CRC Press, 2001.
[13] C. Harito, D.V. Bavykin, M.E. Light, F.C. Walsh, Titanate nanotubes and nanosheets as a mechanical reinforcement of water-soluble polymeric acid: experimental and theoretical studies, Compos. B Eng. 124 (2017) 54–63, https://doi.org/10.1016/j.compositesb.2017.05.051.
[14] P.I. Pontón, L.P. Prisco, B.A. Marinkovic, Effects of low contents of A2M3O12 submicron thermotactic-like fillers on thermal expansion and mechanical properties of HDPE-based composites, Polym. Compos. 39 (S3) (2018) E1833–E1821, https://doi.org/10.1002/pc.24811.
[15] Z. Hashin, S. Shtrikman, A variational approach to the theory of the elastic behaviour of multiphase materials, J. Mech. Phys. Solids 11 (1963) 127–140, https://doi.org/10.1016/0022-5096(63)90060-7.
[16] M. Razlan, H. Akil, M. Helmi, A. Kudus, A.H. Kadarman, Improving flexural and dielectric properties of MWCNT/epoxy nanocomposites by introducing advanced hybrid filler system, Compos. Struct. 132 (2015) 50–64, https://doi.org/10.1016/j.compstruct.2015.05.020.

[17] Y. Zare, K. Yop, Development of Hashin-Shtrikman model to determine the roles and properties of interphases in clay/ CaCO3/PP ternary nanocomposite, Appl. Clay Sci. 137 (2017) 176–182, https://doi.org/10.1016/j.clay.2016.12.033.

[18] Q. Li, R. Liu, T. Wang, K. Xu, Q. Dong, B. Liu, J. Liu, B. Liu, Q. Li, R. Liu, T. Wang, K. Xu, Q. Dong, B. Liu, J. Liu, High pressure synthesis of amorphous TiO2 nanotubes, AIP Adv. (5) (2017) 097128, https://doi.org/10.1063/1.4930916.

[19] D.R. Hummer, P.J. Heaney, Thermal expansion of anatase and rutile between 300 and 575 K using synchrotron powder X-ray diffraction, Powder Diffr. 22 (2007) 352–357, https://doi.org/10.1154/1.2790965.

[20] E. Castillo, J.F. Caldito, Coefficient of thermal expansion of TiO2 filled EVA based nanocomposites. A new insight about the influence of filler particle size in composites, Eur. Polym. J. 49 (2013) 1747–1752, https://doi.org/10.1016/j.eurpolymj.2013.04.023.

[21] P.M. Forster, a.W. Sleight, Negative thermal expansion in Y2W3O12, Int. J. Inorg. Mater. 1 (1999) 123–127, https://doi.org/10.1016/S1466-6049(99)00021-5.

[22] P.S. Turner, Thermal-expansion stresses in reinforced plastics, J. Res. Natl. Bur. Stand. 37 (1946) 239–250, https://doi.org/10.6028/jres.037.015.

[23] R.A. Schapery, Composite materials based on polyolefines, J. Compos. Mater. 2 (1968) 380–404, https://doi.org/10.1177/002199836800200308.