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Mechanical Properties and Creep Characteristics of Wood/PVC Composites at Different Temperatures

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Abstract**—** This paper investigated the effect of temperature on the mechanical properties and tensile creep response of Wood/PVC (WPVC) composite materials. The tensile, compressive, and flexural properties were measured at room temperature, 40°C, 50°C, 60°C and 70°C, respectively. The short term tensile creep at different temperatures was also investigated to obtain the creep characteristics of WPVC composites using power law models. The experimental results summarized that all mechanical properties of WPVC composites decreased significantly by an increasing in temperature, especially for the applied temperatures with higher than 50 °C. The tensile creep models of WPVC composites were obtained for both time-stress dependent and time-stress-temperature dependent. These creep models can be used to predict the long term deformation of WPVC composites for the design phase of WPVC composite structural member.

Keywords—Wood/PVC composites, Mechanical properties, Creep characteristics, Power law model, Temperature effect.

I. Introduction

Wood/poly vinyl chloride (WPVC) composite materials are increasing being used in many new applications, e. g. as construction material in civil engineering projects [1]. The advantages of WPVC composite material are light weight, low water absorption, termite resistance, humidity resistance, environment erosion resistance, dimensional stability and low maintenance requirement. Pulngern et al. [1] indicated that WPVC composites were anisotropic, non-homogeneous, and had lower mechanical properties than natural wood. Moreover, time-dependent properties of flexural creep behavior were also presented in our previous work [2] which found that WPVC composites gave higher creep responses than that of real wood.

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Not only the flexural creep experimental investigation of WPVC composites was presented in our previous work but also the creep simulation or computational investigation of flexural creep responses has been performed [3]. This work simulated the creep responses of WPVC composite members before and after strengthening by HCS flat bar strips. Computer-simulated plots of displacement versus time for WPVC composite members before and after strengthening under various sustained loads were obtained by using the power law model. This model was typically used in the case of wood plastic composites [4] and plastics [5].

Since creep behaviors is a very important in case of construction material in civil engineering projects and only the flexural creep response of WPVC composites was presented previously. Therefore, this work is continuing on this line of research by investigation the tensile creep response of WPVC composites. Moreover, no studies have yet been performed the effect of temperatures on the mechanical properties of WPVC composites. The effect of temperatures is included in this work and it possibly affects on both short and long terms properties of WPVC composites. The obtained results may be of interest to designer who uses the WPVC composites material as structural members.

II. Experimental

2.1 Commercial WPVC Composite Members

The WPVC composite materials consisted of a PVC matrix and wood flour particles. PVC powder was supplied by V.P. Wood Co., Ltd. (Bangkok, Thailand) under the trade name of SIAMVIC- 266RB, having a K value of 66. The other additives, in parts per hundred (pph) of PVC (SIAMVIC-266RB), included a PVC organic complex stabilizer (TS-DBL-Pb-Ba, 3.6 pph), an external lubricant (Finalux G-741, 0.6 pph), calcium carbonate (Omyacarb-2T, 9 pph), calciumstearate (0.3 pph), and acrylic- based processing aids (PA20, 8 pph). The wood flour particles, supplied by V.P. Wood Co., Ltd. (Bangkok Thailand), had an average size of 100 to 300 lm. The content of the wood particles used in the PVC compounds was fixed at 100 pph of PVC powder, the weight ratio of wood flour to PVC being 1: 1. The wood particles were chemically surface treated with 1.0 wt% N-(2-aminoethyl)-3-aminopropyl trimethoxysilane (KBM-603, Mw = 222.4). An industrial-scale twin-screw extruder with counter-rotating screws (KMD-90–36; KraussMaffei Technologies, Munich, Germany) was employed for production of WPVC members. The melt-blending and preparation processes consisted of: (i) drying the KBM-603-treated wood particles at a temperature of 80 8C for 24 h until the weight of wood particles was constant; (ii) dry-blending the PVC compound with the dried

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high-speed mixer of 2,000 rpm for 2 min; (iii) melt-blending in the twin-screw extruder at temperature of 180 8C with screw rotation speed of 15 min–1; (iv) extruding the molten WPVC composites through the die; and (v) passing through a cooling system for composites solidification. The obtained solidified members had a rectangular section with four hollow cores. The section dimensions were 38 mm. 144 mm^2, with a thickness of 6 mm. This section has been widely used for commercial WPVC composite members for decks (flat-wise installation) and substructures of decking system (edge-wise installation), especially in the Southeast Asian region.

2.2 Mechanical properties test at different temperatures

Mechanical properties test at different temperatures consist of tensile, compressive, and flexural tests, respectively. The tensile test was carried out in accordance with ASTM D638 [6] while the compressive test was carried out in accordance with ASTM D6108-13[7]. Finally, the flexural test was carried out in accordance with ASTM D790 [8]. The applied temperatures used were room temperature (RT), 40°C, 50°C, 60°C and 70°C, respectively. Five tested specimens per temperature were determined for the stress–strain relationship as well the mechanical properties of tensile strength and modulus of elasticity by using an Instron universal testing machine (ID: 5969S1121 with capacity of 50kN built in with the oven model of 3119-506 and serial number of 0005860).

2.3 Short term tensile creep test at different temperatures

The tensile creep test of WPVC composites was carried out in accordance with ASTM D638-10 [6]. Three specimens per results were tested by using an Instron universal testing machine (ID: 5969S1121 with capacity of 50kN built in with the oven model of 3119-506 and serial number of 0005860). The initial deformation of the tested specimen and additional deformation as a function of time due to sustained loading were then recorded. In this work, WPVC composites test specimens were subjected to a sustained load for a period of 180 minutes and monitored the changes in deformation at every 0.1 second [9]. The sustained loads used in this experiment were varied from 25%, 40%, and 55% of ultimate loading for the temperature of 50°C in order to represent the effect of applied sustained loads. Another group of specimens were tested with applied sustained load of 40% of ultimate loading at room temperature (RT), 50°C, and 70°C in order to represent the effect of temperatures on creep response. From these designed test specimens, the creep properties of WPVC composites based on the effects of stress levels and temperatures can be discussed.

III. Results and Discussion

3.1 Mechanical properties of WPVC composites at different temperatures

The tensile properties results of WPVC composites are shown in Table 1 while the change in stress-strain relationship of each temperature is presented in Fig. 1. The results indicated tensile strength and modulus of elasticity decrease as increasing in applied temperatures, especially the temperatures which is higher than 50°C.

TABLE 1. TENSILE PROPERTIES OF WPVC COMPOSITES AT DIFFERENT TEMPERATURES

Temperature (°C)	Tensile strength (MPa)	Maximum tensile strain (%)	Modulus of elasticity (MPa)
Room temperature(RT)	24.23	1.21	3,645.98
40	23.06	1.28	3,488.58
50	17.99	1.20	2,919.39
60	14.24	1.49	2,091.56
70	8.93	4.47	1,280.73

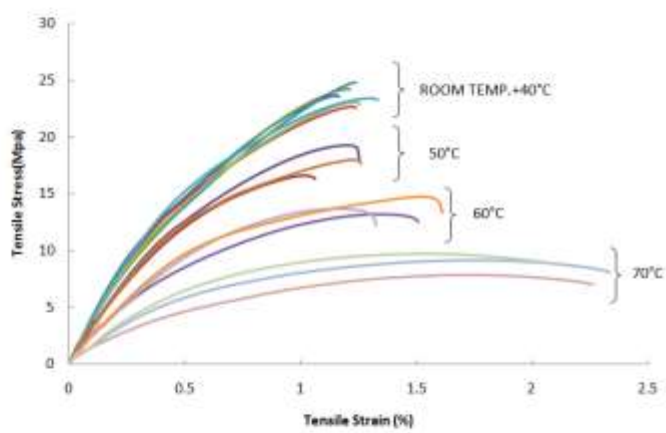

Figure 1. Stress-strain relationship of tensile test at different temperatures

Table 2 presents the change in tensile strength and modulus of elasticity of WPVC composites at different temperatures incomparison with room temperature (RT). The tested results indicate that the tensile properties of WPVC composites decreased slightly at 40 °C. However, the tensile strengths and modulus of elasticity reduce significantly (25.75-63.14% and 19.93-64.87%) when the temperatures are increased in ranged of 50-70°C. These mean that the tensile stress-strain relationship, tensile strength, and modulus of elasticity are temperature dependence. These behaviors also found in case of wood/polypropylene composites and rigid PVC [9].

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TABLE 2. COMPARISON OF TENSILE STRENGTH AND MODULUS OF ELASTIC OF WPVC COMPOSITES WITH CONTROL SPECIMEN AT ROOM TEMPERATURES

Temperature (°C)	Tensile strength (MPa)	Different from control specimen. (%)	Modulus of elasticity (MPa)	Different from control specimen. (%)
Room temperature (RT)	24.23	-	3,645.98	-
40	23.06	4.83	3,488.58	4.32
50	17.99	25.75	2,919.39	19.93
60	14.24	41.23	2,091.56	42.63
70	8.93	63.14	1,280.73	64.87

In case of compressive test results, the compressive strength, maximum compressive strain, and modulus of elasticity of WPVC composites at different temperatures were shown in Table 3 and Fig.2.

TABLE 3. THE COMPRESSIVE PROPERTIES OF WPVC COMPOSITE AT DIFFERENT TEMPERATURES

Temperature (°C)	Compressive strength (MPa)	Maximum compressive strain (%)	Modulus of elasticity (MPa)
Room temperature(RT)	42.76	3.00	2,000.00
40	40.44	3.00	2,000.00
50	34.23	3.00	2,000.00
60	26.47	3.00	1,714.20
70	16.56	3.00	1,100.00

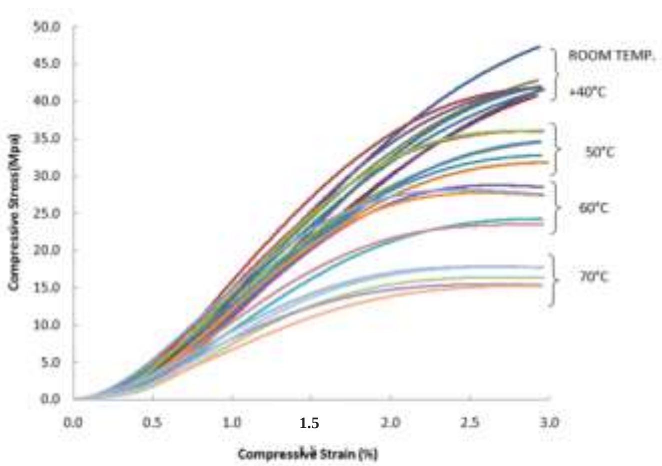

Figure 2. Stress-strain relationship of compressive test at different temperatures

The obtained results indicate that the compressive strength of WPVC composites remain unchanged at temperatures of 40 °C. However, their properties change with an increase in temperature similar as found in case of tensile test. By increasing the temperatures from 50-70 °C, the compressive strength and modulus of elasticity decrease significantly. Table 4 also presented the comparison of compressive strength and modulus of elasticity with control specimen at room temperature (RT). These results indicated that the compressive strength and modulus of elasticity reduced significantly (38.10-61.27% and 14.29-45.00%) when the temperatures is increased to be 60-70 °C, respectively.

TABLE 4. COMPARISON OF COMPRESSIVE STRENGTH AND ELASTIC MODULUS OF WPVC COMPOSITES WITH CONTROL SPECIMEN AT ROOM TEMPERATURE

Temperature (°C)	Compressive strength (MPa)	Different from control specimen. (%)	Modulus of elasticity (MPa)	Different from control specimen. (%)
Room temperature(RT)	42.76	-	2,000.00	-
40	40.44	5.43	2,000.00	0.00
50	34.23	19.95	2,000.00	0.00
60	26.47	38.10	1,714.20	14.29
70	16.56	61.27	1,100.00	45.00

In case of WPVC composites due to flexural test, the results are shown in Table 5 and Fig. 3. Similar behaviors as obtained previously for tensile and compressive tests are found. When the temperatures increased, the flexural properties of WPVC composites were decreased.

TABLE 5. FLEXURAL PROPERTIES OF WPVC COMPOSITES AT DIFFERENT TEMPERATURES

Temperature (°C)	Flexural strength (MPa)	Maximum flexural strain (%)	Modulus of elasticity (MPa)
Room temperature (RT)	32.21	2.077	2,484.44
40	24.61	2.057	2,463.56
50	19.46	2.400	2,280.43
60	17.92	3.014	1,749.10
70	13.11	5.000	1,491.10

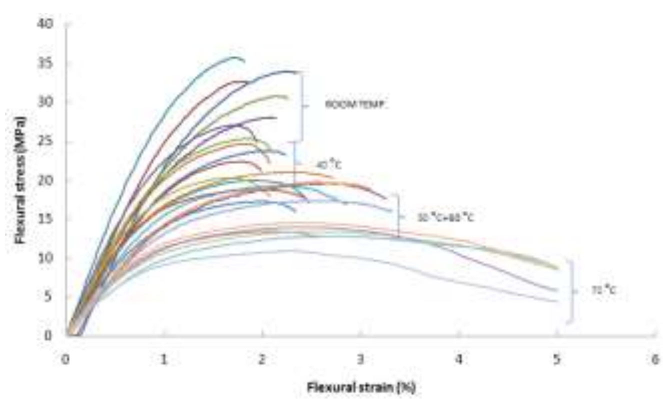

Figure 3. Stress-strain relationship of flexural test at different temperatures

The comparison of flexural strength and modulus of elasticity with control specimen at room temperature (RT) is shown in Table 6. Higher deviations from control specimen at room temperature (44.37-59.32% and 29.60-39.98%) are

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obtained with an increase in temperatures to be 60-70 °C, respectively.

TABLE 6. COMPARISON OF FLEXURAL STRENGTH AND ELASTIC MODULUS OF WPVC COMPOSITES WITH CONTROL SPECIMEN AT ROOM TEMPERATURE

Temperature (°C)	Flexural strength (MPa)	Different from control specimen. (%)	Modulus of elasticity (MPa)	Different from control specimen. (%)
Room temperature(RT)	32.21		2,484.44	
40	24.61	23.59	2,463.56	0.84
50	19.46	39.60	2,280.43	8.21
60	17.92	44.37	1,749.10	29.60
70	13.11	59.32	1,491.10	39.98

The obtained results indicate that all mechanical properties are temperature dependence. Their properties decrease significantly when the temperature increases to be 50°C. In the design phase of WPVC composite member, the effect of temperatures must be included.

3.2 Short term tensile creep response of WPVC composites at different temperature

The tensile creep conditions used in this study are presented in Table 7. The creep response of WPVC composites at different temperature and different stress levels are shown in Fig 4.

TABLE 7. TENSILE CREEP TEST CONDITIONS OF WPVC COMPOSITE AT DIFFERENT TEMPERATURES

Temperature (°C)	Stress levels	Tensile stress (MPa)	Maximum strain (%)	Duration (Min.)
Room temperature (RT)	40%	9.691	0.497	180
50	25%	4.497	0.227	180
	40%	7.195	0.340	180
	55%	9.893	0.544	180
70	40%	3.572	1.365	180

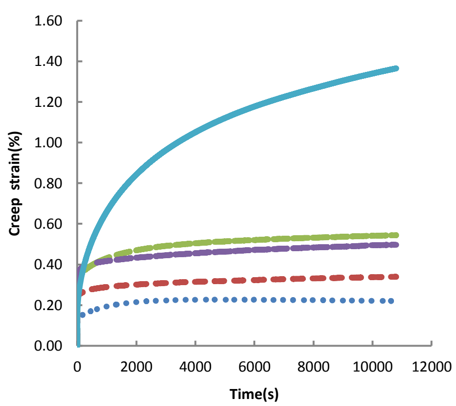

Figure 4. Short-term tensile creep response of WPVC material composite at different temperature and stress level

The obtained results indicate that almost speimens are still in the secondary creep region at the end of experment. Higher creep rate are found in case of high temperatures. At 70°C, tested specimens showed sign of initiation of tertiary creep response. Therefore, the temperature affacted directly on the creep response of WPVC composites.

3.2.1 Creep models with stress and time dependence

To evaluate the creep models with combined time-stress dependence of WPVC composites based on the short term creep test results, the power law creep model proposed by Bailey and Norton [10] is applied. The general form Bailey-Norton law model, which applies well at a constant temperature, is given as follows:

$$\varepsilon_c = a\sigma^b t^n \quad (1)$$

where ε_c = creep strain (in %); σ = stress (in MPa), t = time after loading (in second) and a, n, b are creep parameters Therefore, the creep parameters appearing in (1) must be determined by using the power law equation derived using least-square curve fitting of the results of tensile creep tests. The creep parameters (a and b) were determined for different levels of applied stress (σ)

By using an average value of n from test results conducted at different stress levels, the power law model to predict the creep response of the WPVC composites under sustained tensile stress can be represented by:

$$\varepsilon_c = 0.026\sigma^{0.977}t^{0.081} \quad (2)$$

A comparison of the creep strain predicted by (2) with experimental result is shown in Fig. 5. The results indicated that the proposed creep model yielded a good correlation with the experimental results (R^2 are ranged from 0.788-0.959).

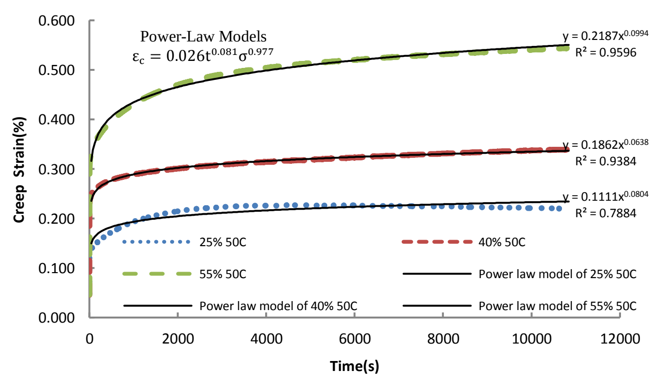

Figure 5. Experimental and predicted tensile creep strains with stress dependence by the power law model at fixed temperature of 50 °

3.2.2 Creep models with stress, time, and temperatures dependence

To evaluate the creep parameters with combined time-temperature-stress dependence of WP

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the short term creep test results, the power law creep model proposed by Pickel et al. [10] is applied. The general form of Pickel's law model is given as follows:

$$\varepsilon_c = a\exp\left(\frac{-A}{T}\right)t^k\sigma^n \qquad (3)$$

where T = temperature (in °C) and a, n, k, A are creep parameters determined using the creep test results.

By using an average value of n from test results conducted at different stress levels, the power law model to predict the creep response of the WPVC composites under sustained tensile stress can be represented by:

$$\varepsilon_c = 0.0252\exp\left(\frac{-9.700}{T}\right)t^{0.0775}\sigma^{0.8561} \qquad (4)$$

A comparison of the creep strain predicted by (4) with experimental result is shown in Fig 6. The results indicated that the proposed creep model yielded a good correlation with the experimental results (R^2 are ranged from 0.788-0.959).

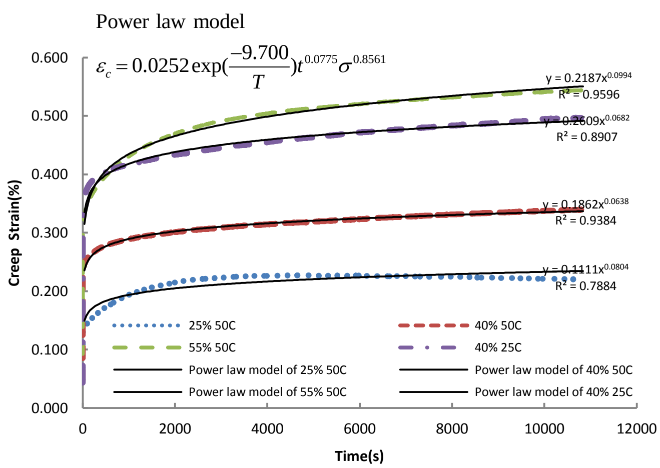

Figure 6. Experimental and predicted tensile creep strains with stress dependence by the power law model for WPVC material composite at 50 °

IV. Conclusion

This research presents the effect of temperature on mechanical properties and creep response of WPVC composites. The test results indicated that

[1] All mechanical properties of WPVC composites decreased with an increase in temperature, especially, the applied temperatures with higher than 50 °C

[2] Creep models combined stress-time dependence and combined stress-time-temperatures for WPVC composites are obtained in this study and show good correlation with those of experimental results.

[3] Temperatures affect directly on mechanical properties as well as creep responses of WPVC composites and should be included in the design phase of WPVC composites structural members.

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