T.C.
ISTANBUL TECHNICAL UNIVERSITY
EARTHQUAKE ENGİNEERING AND DISASTER MANAGEMENT INSTITUTE

ON THE EVALUATION OF WOOD-POLYMER COMPOSITE PROPERTIES

TECHNICAL REPORT

The report number: 2015-539

(This report is prepared within the context of the Istanbul Technical University Working Capital Regulation.)

Prof. Dr. Nihal ARIOĞLU
Dr. M.Serkan YATAĞAN

Istanbul Technical University, 34469 Maslak, İstanbul

İ.T.Ü.
İSTANBUL TEKNİK ÜNİVERSİTESİ
DEPREM MÜHENDİSLİĞİ VE AFET YÖNETİMİ ENSTİTÜSÜ

ON THE EVALUATION OF WOOD-POLYMER COMPOSITE PROPERTIES

TECHNICAL REPORT

The date of the report: 22.05.2015
The report number: 2015/539

(This report is prepared within the context of the Istanbul Technical University Working Capital Regulation.)

I. INTRODUCTION

Hasoğlu Kompozit Yapı Malz.ve Makina San. Tic. Ltd. Şti. has filed in an application to ITU Earthquake Engineering and Disaster Management Institute on 02.03.2015 for the evaluation of the properties of the wood-polymer composites being producing. The respective study has been undertaken in line with the corresponding decision of the Institute Executive Board.

II. TESTS and RESULTS

The physical, mechanical, thermal and the electrical properties of wood-polymer composites which Hasoğlu Kompozit Yapı Malz.ve Makina San. Tic. Ltd. Şti sent to Building Materials Laboratory are determined with the experiments and the results are obtained.

1. The Physical Properties

The physical properties such as the dynamic friction coefficient, the linear mass, the dimensional tolerance and the deviation from the straightness are determined.

1.1 The Dynamic Friction Coefficient

According to TS EN 13893, (Dynamic Friction Coefficient should be **≥ 0,43)** the material with the specific weight is put on the wood-polymer composite and this material is pulled out by the force, Fig-1. The friction force is recorded when the material moves. This test is practiced on two surfaces of the sample. As a result of the measurement, the dynamic friction coefficient is calculated with the formula $Fs = \mu . N$ (F_s: The Friction Force, μ : The Dynamic Friction Coefficient, N: Normal Force) as **0,48**.
In this case, a condition required by the standard to ensure that **0.48 ≥ 0.43**.

Figure 1. The Dynamic Friction Test

1.2 The Linear Mass

In the regard of TS EN 15534-1 and TS EN 15534-4, (Linear mass should be **≥ % 95**) the lengths and the weights of 3 wood-polymer composites are measured as mm and gr. The average of the measurements of the length and the weight is calculated and then the linear mass is calculated with the formula $P = M / L$ [P: Linear mass (gr/m), M: The weight of the sample (gr), L: The length of the sample (m)]. In the standard, the tolerance of the linear mass is determined as the percentage. The average of the wood-polymer composites is 0,281 gr/m and the tolerance is 99,6 %.

In this case, a condition required by the standard to ensure that **% 99,6 ≥ % 95.**

1.3 The Dimensional Tolerance

According to TS EN 15534-1 and TS EN 15534-4, the lengths, the widths and the thicknesses of wood-polymer composites are measured and the averages of every dimensions are calculated. In Table 1, these averages are demonstrated.

Table 1. The Dimensional Tolerance

The Dimensions	Tolerance
The Length	± 0,05 cm
The Thickness	± 0,23 cm
The Width	± 0,02 cm

1.4 The Deviation from the Straightness

In the TS EN 15534-1 and TS EN 15534-4, (The Deviation from the Straightness should be **≤ 0,50 %)** 3 wood-polymer composites are settled on the flat plane and the dimension of the space between the sample and plane in order to obtain the deviation from the straightness. The deviation of wood-polymer composites are measured as **± 0,40 %**.

In this case, a condition required by the standard to ensure that **0,40 % ≤ 0,50 %.**

2. The Mechanical Properties

The mechanical properties such as the impact and flexural strengths and the creep are determined.

2.1 The Impact Strength

In the regard of TS EN 15534-1, (if depth of residual indentation is bigger than 0,5 mm, the sample is damaged), the weight is fall down on the wood-polymer composite from the specific height. In the end of the test, the sample is observed visually whether if there is a damage on the sample. 10 wood-polymer composites are tested. The impact strength is tested on both surfaces of the sample, Fi-2. The weight is determined as 1 000 ± 5 gr in the standard, the height is 700 ± 5 mm. In the visual observation, the cracks or the bruise are investigated on the sample. As a result of the investigation, there is no crack but there is a light bruise. The depth of the bruise is measured as 0,01 mm. The depth of residual indentation is smaller than 0,5 mm. This case was determined to be high impact strength of the samples.

Figure 2. The Impact Strength Test (Steel Ball Test)

2.2 The Flexural Properties

According to TS EN 15534-1, (Deflection under a load of 500 N ≤ 2,0 mm arithmetic mean value), the thicknesses and the widths of 8 wood-polymer composites are measured. The distance between the supports are chosen as 40 cm (the distance should be at least 10 cm),Fig-3. The sample is settled on the supports and 3 bending points are tested. The deformations of the loads are recorded with the comparometer. (The maximum force is also recorded) in Figure 1. In the standard, for the suitable flexural properties, the average deformation in the sample at 500 N should be equal to and smaller than 2 mm. The deformation in the wood-polymer composite at 500 N is recorded as 1,77 mm and it is suitable to the standard. The elasticity modulus and the bending strength are calculated with below formula.

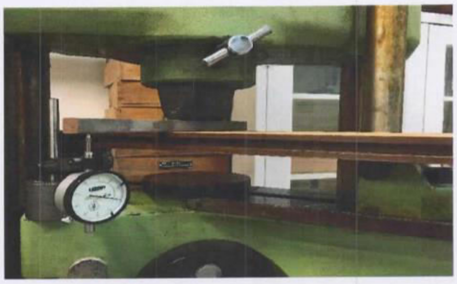


Figure 3. The bending strength test

The formula of elasticity modulus:

$$E_m = \frac{l_1^3 \cdot (F_2 - F_1)}{4 \cdot b \cdot h^3 \cdot (a_2 - a_1)}$$

E_m : The elasticity modulus

l_1 : The distance between the supports (mm)

$F_2 - F_1$: The constant difference between the loads in the linear part of the strain-stress graphic (N). F_2, 20 % of the maximum force, F1, 10 % of the maximum force

b : The width of th sample (mm)

h : The thickness of the sample (mm)

$a_2 - a_1$: The deformations at F_2 and F_1 (mm)

The formula of bending strength:

$$\sigma_m = \frac{M_B}{W_x} = \frac{F_{max} \cdot l_1}{4 \cdot W_x}$$

σ_m : The bending strength

F_{max} : The maximum force (N)

l_1 : The distance between the supports (mm)

W_x : The section moment (mm^3)

The elasticity modulus and the bending strength of wood-polymer composites are calculated as 3,8 GPa and 796 MPa relatively. In the literature, when the amount of the wood increases, the elasticity modulus increases. These results support this evaluation.

2.3 Creep

In TS EN 15534-1, (the standart limits are given in table2), the creep behavior of wood-polymer composites is investigated by loading the sample constantly in 3 bending points test,Fig.4.. The distance between the supports are chosen as 90 cm and the length of the sample is equal to the distance between the supports. Every sample is settled on the supports and is loaded on the middle part of the sample constantly for 3 weeks. The deformations are recorded as mm by the comparometer which is settled under

the sample at the specific times in the standards. (Figure 2). The creep is calculated with below formula with these measurements.

Figure 4. The creep behavior

The creep calculation:

$$\Delta_s = a_3 - a_2$$

Δ_s : The amount of creep (mm)

a_2 : The deformation at 1 min after loading (mm)

a_3 : The deformation at 24 hours before unloading (mm)

$$\Delta_{sr} = a_4 - a_1$$

Δ_{sr} : The residual amount of creep (mm)

a_1 : The deformation before loading (mm)

a_4 : The deformation at 24 hours after unloading (mm)

$$C_f = \frac{a_3 - a_2}{a_2 - a_1}$$

C_f : The creep factor

a_1 : The deformation before loading (mm)

a_2 : The deformation at 1 min after loading (mm)

a_3 : The deformation at the end of loading before unloading (mm)

$$E_{rc} = 100 \times \frac{a_3 - a_5}{a_3 - a_1}$$

E_{rc} : The creep recovery (%)

a_1 : The deformation before loading (mm)

a_3 : The deformation at the end of loading before unloading (mm)

a_5 : The deformation at 24 hours after unloading (mm)

The values of the creep are revealed in Table 2.

Table 2. The values of creep

Creep	Values (mm)	Standard Values (mm)
The amount of creep (Δ_s)	6,13	≤ 10
The residual amount of creep (Δ_{sr})	4,88	≤ 5
The creep factor (C_f)	2,03	≤ 6
The creep recovery (E_{rc})	47	≥ 30

* Individual amount of creep Δ_s of the sample should be ≤ 13.

The creep is suitable to the standard.

3. The Durability Tests

The durability tests such as the artificial weathering, swelling and water absorption, freezing-thawing, boiling test and wetting-drying are determined.

3.1 The Artificial Weathering

In TS EN 927-6, the wood-polymer composites are held under UV lamp for the specific time(Fig.5). In the end of the test, the color change is investigated visually.

Figure 5. The artificial weathering (UV test)

3.2 Swelling and Water Absorption

In the regard of TS EN 15534-1, (the standart limits are given in table 3), the thicknesses, the widths, the lengths and the weights of 5 samples are measured and then the samples are put in 23°C water. At 24 hours, 2, 4, 7, 14 and 28.days, the thicknesses, the widths, the lengths and the weights of 5 samples are premeasured. The measurements and the limits are demonstrated in Table 3.Except the thickness, the other dimensions are suitable to the standard.

Table 3. The change in dimensions in the swelling and water absorption test

Dimensions	Swelling (%)	Water Absorption (%)	Standard Limits
The thickness	5,6	-	≤ 4
The width	0,77	-	≤ 0,8
The length	0,31	-	≤ 0,4
The wieght	-	1	≤ 7

Figure 6. Water Absorption Test

3.3 Freezing-Thawing

In TS EN 321, (the standart limits are given in table 4) after the water absorption test, in the first cycle of the freezing-thawing, the wood-polymer composites are put in the freezer for 24 hours and then they are dried for 3 days. In the second and third cycles, the samples are saturated with water again, they are put in the freezer for 24 hours and dried for 3 days. After the cycles, the samples are dried in the oven. The elasticity modulus and the bending strength of the samples are tested again and the amount of the decrease is determined as the percentage. In Table 4, the change in the elasticity modulus and the bending strength is demonstrated.

Figure 7. The freezing-thawing test

Table 4. The change in the elasticity modulus and the bending strength in the normal and freezing-thawing conditions

Mechanical Properties	Normal (MPa)	Freezing-Thawing (MPa)	Decrease (%)	Standard Limits (%)
The Bending Strength	796	713	10	≤ 20
The Elasticity Modulus	3,8	3,53	7	≤ 20

The decrease in the bending strength and the elasticity modulus supply the standard limits.

3.4 Boiling Test

In TS EN 15534-1, (average water absorption should be ≤ % 7), at first the weights of the samples are measured and put in the boiling water till the boiling point. The samples are held in the boiling water for 5 hours and then the samples are taken out from the water and put in the cold water for 15 minutes. After 15 minutes, the samples are taken out and held in room temperature. After 2 hours, the weights of the samples are weighed again.

As a result of the calculations, the average water absorption by the boiling is % 3,3. İn this case water absorption of the samples supply the standart limit.

3.5. Wetting - Drying

In TS EN 15534-1, (average water absorption should be ≤ % 7), In one cycle of the wetting-drying, 3 wood-polymer composites are held in water for 18 hours and dried in the room temperature for 6 hours. The test concepts of 7 cycles. At first, the weights of the samples are measured and after 7 cycles, the weights are measured again. The difference between the weights is calculated as 1 %. This value supply the standard limit which is smaller than 7 %.

4. Thermal Properties

In the concept of the thermal properties, the linear thermal expansion coefficient, the heat build-up and the heat reversion are investigated.

4.1 The Linear Thermal Expansion Coefficient

According to TS 1065-2 ISO 11359-2,(The Linear Thermal Expansion Coefficient should be $\leq 50 \times 10^{-6}\ K^{-1}$),5 mm x 5 mm 3 prism samples are prepared and are settled between the probes of Thermal Mechanical Analysis instrument. The amount of heat is measured by loading the sample with 4 $\pm$ 0,1 kPa. The velocity of dry air current has 50 mL/min. The minimum temperature of the sample is 5°C/min and is increased with the constant velocity. The change in the length is recorded for every temperature.

The linear thermal expansion coefficient (α) at T temperature is calculated as K^{-1} with below formula:

$$\alpha = (dL/dT) \times 1/L_o$$

L_0: The length of the sample at room temperature (μm)

L: The length of the sample at T temperature (μm)

T: Temperature (K)

The linear thermal expansion coefficient of wood-polymer composites are calculated as $10 \times 10^{-6}\ K^{-1}$ and supply the standard limit which is $\leq 50 \times 10^{-6}\ K^{-1}$.

İn this case the linear thermal expansion coefficient of the samples supply the standart limit.

4.2. The Heat-Build up Test

According to TS 15534, (The heat-build up should be between 35-45°C), 3 wood-polymer composites are held under 400 W UV lamp with 75 cm distance. The surface and the ambient temperature are measured with the digital thermometer. The difference between the surface and the ambient temperature is the heat-build up temperature and is approximately 38°C.
İn this case the heat-build of the samples are in the standart range.

4.3 Heat Reversion

IN ASTM 610, (There is no deformation at 150°C), 3 wood-polymer composites are put in 150°C oven for 30 minutes which is the specific time for the thickness. After 30 minutes, there are a little bit deformations in the sample.

5. The Electrical Resistance

The Electrical Resistance of wood-polymer composites are measured with the ohm meter. The electrical resistance of 3 samples is measured as the numerical value by giving the low and high voltage As a result of the measurements, the electrical resistance of wood-polymer composites are determined forever and the electricity conductivity is 0.

6. The Fire Resistance

In the concept of the Fire Resistance Single flame source and Radiant Heat Source are investigated.

6.1 Single flame source test

According to TS EN ISO 11925-2, a single flame is practiced on the corner or the surface of 3 wood-polymer composites for 20 seconds, Fig.-8. In the end of the test, there are burning-out and smoke and the height of the flame is 7-8 cm. However, there is no dripping. According to TS EN 13501-1, when the height of the flame is smaller than 15 cm, the wood-polymer composites are C_{fl} s1 in the fire classification for the floor materials.

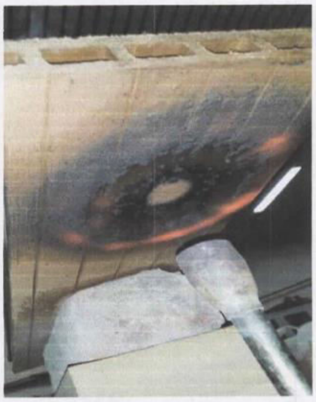

(a) Beginning of the experiment **(b)** End Try

Figure 8. Single flame source test

6.2 Radiant Heat Source Test

In EN ISO 9239-1, (the critical heat flux should be ≥ 4,5 kW/m^2), the approximately 300°C flame is practiced under the surface of the sample for 20 seconds, Fig.-9. In the end of the test, there are burning-out from the surface to inner parts and smoke. However, there is no dripping.

According to Fourier's Law, the heat flux is calculated as 4,8 kW/m^2. According to TS EN 13501-1, the wood-polymer composites are C_{fl} s1 in the fire classification for the floor materials.




(a) Spread of flame, **(b)** Formation of smoke

Figure 9. Radiant Heat Source Test

III. CONCLUSIONS AND EVALUATIONS

The results of the experiments and visual evaluations conducted on the wood-polymer composites have revealed that the following are all in accordance with the respective standards:

- The physical properties such as the dynamic friction coefficient, linear mass, dimensional tolerance and the deviation from straightness;
- the mechanical properties such as the impact and flexural strengths and the creep;
- the durability properties such as artificial weathering (UV resistance), swelling and water absorption (except for thickness), freezing-thawing, boiling, water absorption and wetting-drying; and
- the thermal properties such as the linear thermal expansion coefficient, heat build-up and heat reversion.

The other findings can be listed as the following:

- The electrical resistance of the wood-polymer composites is infinite; in other words, they are nonconducting.
- The fire class of the composites is Cfl s1.
- The minimal changes in the thickness of the composites can be eliminated by changing or improving the wooden components.

Prof.Dr. Nihal ARIOĞLU
Building Materials Lab.Director

Dr. Müh. M. Serkan YATAĞAN
İTÜ.Arch.Fak. Lecturer