Impacts of Impregnation with Imersol-Aqua on the Modulus of Elasticity in Bending

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ABSTRACT: The aim of this study was to investigate the effects of impregnation with Imersol-Aqua (I-AQUA) on the modulus of elasticity in bending of some woods. For our study, Oriental beech (*Fagus orientalis* Lipsky), oak (*Quercus petrea* Liebl.), Scotch pine (*Pinus sylvestris* Lipsky), Uludağ fir (*Abies Bornmülleriana* Lipsky), Oriental spruce (*Picea orientalis* Lipsky), and poplar (*Populus nigra* L.) wood samples were prepared according to TS EN (Turkish Standards; European Norm) 408 and impregnated with I-AQUA by the method of short-, medium-, and long-term dipping according to ASTM D 1413 and producers' definition. After the impregnation process, modulus of elasticity was measured according to TS EN 408. Consequently, among the nonimpregnated wood samples, modulus of elasticity was found to be the highest in Oriental beech (*Fagus orientalis* Lipsky), (12,490 N mm^{-2}) and the lowest in poplar (5439 N mm^{-2}). As for the period of dipping, the highest modulus of elasticity was obtained in short-term dipping and the lowest in long-term dipping. Considering the interaction of wood type and period of impregnation, the highest modulus of elasticity in bending was obtained in Oriental beech (*Fagus orientalis* Lipsky) with short-term dipping (10,720 N mm^{-2}) whereas the lowest was in poplar with long-term dipping (4597 N mm^{-2}). In consequence, in massive constructions and furniture elements where the modulus of elasticity in bending after impregnation is of great concern, short term impregnation of Oriental beech and Scotch pine materials could be recommended. J Appl Polym Sci 99: 3210–3217, 2006

Key words: mechanical properties; modulus of elasticity; impregnation; wood materials

INTRODUCTION

If the wood materials are used without processing by preventive chemicals (with regard to the area of usage), fungal stains, insect infestation, humidity, fire, etc., damage the wood. As a result of these damages, the woods require to be repaired, maintained, or replaced before their economic life ends.[1] For this reason, in most places the wood materials should be impregnated with some chemicals.[2] In case wood is not impregnated but only painted and varnished instead, the protection on the surfaces is limited to a maximum of two years.[3]

It is reported that, in mines, as a result of the impregnation of the beech and spruce wood with water-soluble salts, the bending, tensile, and impact strength decreased a little, whereas compression strength increased.[4] In another research concerning the impregnation of pine, spruce, fir, beech and poplar woods with Antrasen, it was found that the compression strength increased by 6–40% and the bending strength increased by 10–22%.[5] In the impregnation of pine and beech wood with UA salts and tar oil, the tar oil increased the compression strength by 10% and UA salts increased the same at a lower rate. On the other hand, the tar oil increased the bending strength whereas the UA salts diminished the bending strength.[6]

Vologdin[7] declared that among the materials used for the impregnation of pine, sodium pentaclorfenet, copper sulfate, and sodium fluoride increased the compression strength respectively, by 95%, 25%, and 3%, whereas zinc chloride decreased the compression strength by 9%. Sodium pentaclorfenet also increased the bending strength.[7] In another study, pressure treatment caused a decrease of 8–10% in the bending strength of different wood types.[8]

It was assessed that salty impregnation materials increased the compression strength by 4.6–9.6%, whereas decreased the bending strength by 2.9–16%.[9] In another study, chromate copper arsenate (CCA) and arsenate copper arsenate salts did not cause any significant impact on the modulus of elasticity in bending.[10]

After the impregnation of pine wood samples by hot–cold open tank method with 11 preventives, no significant difference was observed in the bending strength except for a decrease in strength by fluotox-containing acid florid.[11]

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In this study, Oriental beech (*Fagus orientalis* Lipsky), oak (*Quercus petrea* Liebl.), Scotch pine (*Pinus sylvestris* Lipsky), Uludağ fir (*Abies Bornmülleriana* Lipsky), Oriental spruce (*Picea orientalis* Lipsky), and poplar (*Populus nigra* L.) woods commonly being used in furniture manufacturing were examined with respect to the impacts of impregnation with Imersol-Aqua (I-AQUA) on the modulus of elasticity in bending.

EXPERIMENTAL

Wood materials

The woods to be used as test samples were randomly selected from the timber merchants of Ankara. Great pains were taken for the selection of wood materials. Accordingly, nondeficient, proper, knotless, normally grown (without zone line, reaction wood, and decay as well as insect or fungal damages) wood materials were selected.

Impregnation material

Imersol-Aqua (I-AQUA) used as an impregnation material in this study was supplied from Hemel (HEMEL-HICKSON Timber Products Ltd.), Istanbul. I-AQUA is a nonflammable, odorless, fluent, water based, completely water soluble, noncorrosive material with a pH value of 7 and a density of 1.03 g cm^{-3}. It is available as ready-made solution. It contains 0.5% w/w tebuconazole, 0.5% w/w propiconazole, 1% w/w 3-iodo-2-propynl-butyl carbonate, and 0.5% w/w cypermethrin. Before the application of I-AQUA on the wood material, all kinds of drilling, cutting, turning, and milling operations should be completed, and the relative humidity should be in equilibrium with the test environment. In the impregnation process, dipping duration should at least be 6 min, and the impregnation pool must contain at least 15 L of impregnation material for 1 m^3 of wood. The impregnated wood should be left to dry for at least 24 h. The wood material can be painted, varnished, or glued after it is fully dried.[12]

Determination of density

The densities of wood materials used for the preparation of test samples were determined according to TS (Turkish Standards) 2472.[13] For determining the air-dry density, the test samples with a dimension of 20 × 30 × 30 mm^3 were kept under the conditions of 20°C ± 2°C and 65% ± 5% relative humidity until they reached a stable weight. The weights were measured with an analytic scale of ±0.01-g sensitivity. Afterwards, the dimensions were measured with a digital compass of ±0.01 mm. The air-dried densities (δ_{12}) of the samples were calculated with the following formula:

$$\delta_{12} = \frac{M_{12}}{V_{12}} \ (\text{g cm}^{-3}) \tag{1}$$

where, M_{12} is the air-dry weight (g) and V_{12} is the volume (cm^3) at air-dry conditions.

The samples were kept at a temperature of 103°C ± 2°C in the drying oven until they reached a stable weight for the assessment of full-dry density. Afterwards, full-dried samples were cooled in the desiccator containing CaCl. Then, they were weighted on a scale of ±0.01-g sensitivity and their dimensions were measured with a compass of ±0.01-mm sensitivity. The volumes of the samples were determined by stereometric method and the densities (δ_o) were calculated by the following equation:

$$\delta_o = \frac{M_o}{V_o} \ (\text{g cm}^{-3}) \tag{2}$$

where, M_o is the full-dry weight (g) and V_o is the full dry volume (cm^3) of the wood material.

Determination of humidity

The humidity of test samples before and after the impregnation process was determined according to TS 2471.[14]:The samples with a dimension of 20 × 20 × 20 mm^3 were weighed and then oven dried at 103°C ± 2°C till they reached a constant weight. Then, the samples were cooled in a desiccator containing calcium chloride (CaCl) and weighed with an analytic scale of 0.01-g sensitivity. The humidity of the samples (r) was calculated by the following formula:

$$r = \frac{M_r - M_o}{M_o} \times 100 \ (\text{g g}^{-1}) \tag{3}$$

where, M_r is the initial weight of the samples (g) and M_o is the final dry weight (oven-dry) of the samples (g).

Preparation of the test specimens

The rough drafts for the preparation test and control samples were cut from the sapwood parts of massive woods and conditioned at a temperature of 20°C ± 2°C and 65% ± 3% relative humidity for three months until an equilibrium in the humidity distribution was reached. The samples with a dimension of 20 × 20 × 400 mm^3 were cut from the drafts having an average humidity of 12% according to TS EN (European Norm) 408.[15] The densities and humidity values of all test samples were measured before the impregnation process.

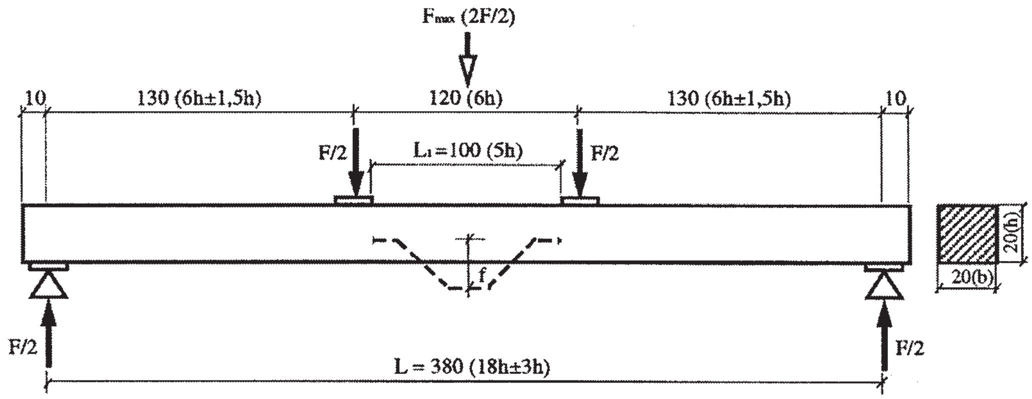

Figure 1 Universal Testing Equipment used for the determination of the modulus of elasticity in bending (dimensions are in millimeters).

The test samples were impregnated according to ASTM D 1413,[16] TS 344,[17] and TS 345.[18] The samples were dipped in the impregnation pool, immersing 1 cm below the upper surface for 10 min in short-term dipping, 2 h for medium-term dipping, and 5 days for long-term dipping.[19] The specifications of the impregnation solution were determined before and after the process.

The processes were carried out at 20°C ± 2°C.[20] Retention of impregnation material (R) was calculated using the following formula:

$$R = \frac{GC}{V} \times 10^3 (\text{kg m}^{-3}) \tag{4}$$

$$G = T_2 - T_1 (g) \tag{5}$$

where, G is the amount of impregnation solution absorbed by the sample (g), T_2 is the sample weight after the impregnation (g), T_1 is the sample weight before the impregnation (g), C is the concentration (%) of the impregnation solution, and V is the volume of the samples (cm^3).

TABLE I
Full-Dry Densities of Wood Materials (g cm^{-3})

Impregnation methods	Oriental Beech	Oak	Scotch pine	Uludag fir	Oriental spruce	Poplar
Control						
Min	0.605	0.596	0.512	0.349	0.388	0.294
Max	0.679	0.572	0.572	0.406	0.435	0.327
x	*0.657*	*0.652*	*0.537*	*0.380*	*0.405*	*0.306*
Ss	0.0196471	0.0206274	0.016681	0.0192202	0.0154602	0.0104193
v	0.0003862	0.0002782	0.000278	0.0003694	0.0002390	0.0001085
Short-term dipping						
Min	0.638	0.606	0.524	0.352	0.393	0.298
Max	0.685	0.698	0.566	0.426	0.425	0.344
x	*0.658*	*0.655*	*0.543*	*0.382*	*0.408*	*0.315*
Ss	0.0136902	0.0266076	0.011758	0.0228182	0.0105399	0.0114603
v	0.0001871	0.0007081	0.000138	0.0005206	0.0001112	0.0002132
Medium-term dipping						
Min	0.642	0.625	0.525	0.355	0.398	0.302
Max	0.692	0.705	0.582	0.431	0.427	0.355
x	*0.661*	*0.659*	*0.561*	*0.389*	*0.409*	*0.320*
Ss	0.014393	0.0228728	0.017394	0.0214683	0.0091044	0.0156931
v	0.000207	0.0005232	0.000302	0.0004608	0.0000828	0.0002462
Long-term dipping						
Min	0.644	0.631	0.542	0.365	0.401	0.306
Max	0.698	0.708	0.596	0.444	0.438	0.368
x	*0.666*	*0.665*	*0.568*	*0.396*	*0.414*	*0.325*
Ss	0.015125	0.0203608	0.014726	0.0223757	0.0111624	0.0169411
v	0.000229	0.0004146	0.000216	0.0005006	0.0001246	0.0002870

x, Average; Min, minumum; Max, maximum; Ss, Standard deviation; *v*, variance.

TABLE II
Air-Dry Densities of Wood Materials (g cm^{-3})

Impregnation methods	Oriental beech	Oak	Scotch pine	Uludag fir	Oriental spruce	Poplar
Control						
Min	0.655	0.655	0.555	0.385	0.401	0.311
Max	0.705	0.699	0.592	0.412	0.441	0.362
x	*0.679*	*0.672*	*0.577*	*0.401*	*0.420*	*0.340*
Ss	0.01678101	0.01382290	0.0121909	0.00922841	0.01435143	0.01679935
v	0.00028202	0.00014860	0.0001486	0.00008546	0.00020596	0.00028222
Short-term dipping						
Min	0.662	0.658	0.558	0.392	0.407	0.320
Max	0.708	0.702	0.600	0.415	0.455	0.371
x	*0.682*	*0.676*	*0.579*	*0.407*	*0.428*	*0.346*
Ss	0.01669811	0.01422672	0.0002416	0.00700391	0.01238621	0.01683935
v	0.00027920	0.00020241	0.0002416	0.00004905	0.00012340	0.00028356
Medium-term dipping						
Min	0.668	0.664	0.578	0.399	0.412	0.325
Max	0.716	0.704	0.605	0.422	0.460	0.380
x	*0.689*	*0.678*	*0.592*	*0.410*	*0.437*	*0.349*
Ss	0.01648220	0.01297760	0.0076324	0.00607379	0.01568961	0.01558080
v	0.00027200	0.00016840	0.0000582	0.00003689	0.00024616	0.00024240
Long-term dipping						
Min	0.669	0.667	0.579	0.408	0.422	0.333
Max	0.722	0.709	0.612	0.444	0.462	0.384
x	*0.695*	*0.683*	*0.597*	*0.419*	*0.440*	*0.352*
Ss	0.01485321	0.01312320	0.0098322	0.01106592	0.01436029	0.01461560
v	0.00022120	0.00017221	0.0000966	0.00012245	0.00020621	0.00021360

x, Average; Min, minumum; Max, maximum; Ss, Standard deviation; *v*, variance.

Impregnated test samples were kept under a temperature of 20°C ± 2°C and 65% ± 3% relative humidity until they reached a stable weight.

Modulus of elasticity in bending

The tests for modulus of elasticity in bending were carried out with the Universal Testing Equipment shown in Figure 1, according to TS EN 408.

The capacity of the Universal Testing Equipment was 400 N. Deformations on the test samples were measured in the middle of the specimen within a zone of five times the width of the sample by comparator. The deformations by incrementally increasing the forces were assessed with a sensitivity of 0.01 mm.

In the elastic deformation zone, the modulus of elasticity (MOE) was calculated with the following formula:

$$MOE = \frac{\Delta F L^3}{4\ b\ h^3\ \Delta f} (\text{Nmm}^{-2}) \qquad (6)$$

where, ΔF is the difference between the arithmetic average of the upper and the lower limits of applied force in the elastic deformation zone (N), Δf is the net elastic deflection—difference between the measured elastic deflection in the upper and the lower loading limits—(mm), L is the span (mm), b is the cross-sectional width of the test sample (mm), and h is the cross-sectional thickness of the test sample (mm).

Data analysis

A total of 24 treatment groups were obtained with six different kinds of wood materials, three different impregnation dipping methods, and one control sample. Eleven replications were made in each treatment group. Thus, a total of 264 samples (6 × 4 × 11) were prepared. The effects of wood material and impregnation method on the modulus of elasticity in bending were analyzed by ANOVA (Analysis of variance). Duncan's multiple range test was also applied wherever appropriate.

RESULTS AND DISCUSSION

Full-dry density

Statistical values for the full-dry densities of test samples impregnated with I-AQUA are given in Table I. As seen from the table, full-dry density values vary according to the type of wood and the impregnation

TABLE III
Retention Amounts in Wood Materials (kg m^{-3})

Impregnation methods	Oriental beech	Oak	Scotch pine	Uludag fir	Oriental spruce	Poplar
Short-term dipping						
Min	109.462	19.022	36.231	32.124	54.321	44.445
Max	130.226	26.546	47.012	50.214	62.358	52.234
x	*120.178*	*22.484*	*43.289*	*45.950*	*58.704*	*48.083*
Ss	7.9475874	2.689613	3.413306	4.020328	3.135393	2.634260
v	63.164146	7.234019	11.65066	16.16304	9.830689	6.939328
Medium-term dipping						
Min	268.256	42.521	65.321	75.021	88.452	69.032
Max	281.356	49.357	75.265	82.854	95.985	80.265
x	*274.728*	*44.936*	*68.538*	*79.180*	*92.225*	*75.405*
Ss	4.870316	2.093756	3.260492	2.489244	2.365208	4.177241
v	23.719986	4.383817	10.630811	6.196337	5.594210	17.44934
Long-term dipping						
Min	355.654	212.854	159.654	205.213	203.568	319.256
Max	375.954	235.987	176.654	229.564	214.002	333.008
x	*365.691*	*218.851*	*167.369*	*216.472*	*209.076*	*327.112*
Ss	7.433700	6.190976	6.165483	7.370773	3.435018	4.636656
v	55.256903	38.32818	38.013184	54.32830	11.799354	21.49858

x, Average; Min, minumum; Max, maximum; Ss, Standard deviation; *v*, variance.

period. The full-dry densities of Scotch pine, fir, spruce, and poplar increase as the impregnation period increases. In Oriental beech and oak, the densities of the control and other treatment groups (short-, medium- and long-term impregnation samples) were found to be approximately similar.

Air-dry density

Statistical values for the air–dry densities of samples impregnated with I-AQUA are given in Table II. As seen from Table II, air-dry densities of wood species increased with the increase in the impregnation period. Oriental beech specimens have the highest air-dry density both within the control and within the three impregnation periods. In contrast, poplar specimens have the lowest air-dry density in all treatment groups.

Peculiarities of impregnation solutions

The pH value and the density of I-AQUA used for the impregnation process did not change either prior or after the impregnation. This may be due to the use of fresh solution in each impregnation process.

Retention quantities

The quantities of retention in relation to wood species and impregnation period are shown in Table III. The amount of retention changed depending on the type of wood and the period of impregnation. The highest retention amount was obtained in Oriental beech for long-term dipping, and the lowest was in oak for short-term dipping. The retention amounts enhanced in all wood species because of the increase in the dipping period. The amount of retention was found to be higher in broad-leaved wood than in needle-leaved wood. As the impregnation period increased, the

TABLE IV
Average Modulus of Elasticity in Bending in Relation to Wood Type and Impregnation Period

	σ_k (N mm^{-})
Wood type*	
I	10710 a
II	10350 b
III	9725 f
IV	7601 c
V	7288 d
VI	4976 e
Impregnation method**	
C	9093 a
S	8414 b
M	8317 b
L	7951 c

* Different letters in the columns refer to significant changes among wood types at 0.05 confidence level ($LSD_{0.5}$ = 125.0).

** Different letters in the columns refer to significant changes among impregnation methods at 0.05 confidence level ($LSD_{0.5}$ = 102.1).

I: Oriental Beech, II: Oak, III: Scotch pine, IV: Uludag Fir, V: Oriental Spruce, VI: Poplar, C: Control, S: Short-term dipping, M: Medium-term dipping, L: Long-term dipping.

TABLE V
Average Modulus of Elasticity in Bending for the Interaction of Wood Type and Impregnation Period (N mm^{-2})

Impregnation methods	Oriental Beech	Oak	Scotch pine	Uludag fir	Oriental spruce	Poplar
Control	12,490	11,800	9,042	7,601	8,172	5,449
S	10,720	10,380	9,377	7,410	7,616	4,985
M	9,960	10,030	10,090	7,485	7,457	4,875
L	9,660	9,239	10,400	6,656	7,160	4,597

S, Short-term dipping; M, Medium-term dipping; L, Long-term dipping.

amount of retention increased. The highest amount of retention was found in the long-term dipping for all wood species. The highest retention amount obtained in Oriental beech for each dipping period could be attributable to the impact of permeability.

Modulus of elasticity in bending

The average values of modulus of elasticity in bending as a function of the wood type and the impregnation period are given in Table IV. The average values of the interaction between the wood type and impregnation material and the results of variance analysis regarding the impacts of wood type and impregnation period on the modulus of elasticity in bending are given in Table V and Table VI, respectively.

Generally, the modulus of elasticity in bending was found to be the highest in Oriental beech and the lowest in poplar. It is probably due to the higher density of Oriental beech when compared with that of the other tested wood materials. As to the impregnation period, modulus of elasticity in bending was found to be the highest in short-term dipping and the lowest in long-term dipping. It can be derived from these results that the modulus of elasticity in bending decreased with the increase in dipping period. The average values of the modulus of elasticity concerning the interaction of wood material and impregnation period are given in Table V.

In all wood materials excluding Scotch pine, modulus of elasticity in bending decreased as the impregnation period increased. It can be a result of less interaction between the wood fiber and the impregnation material in Scotch pine. As a matter of fact, it is acknowledged that pine species are more resistant to chemical materials than are other wood types.[21] The analysis of variance concerning the impacts of wood material and impregnation period on the modulus of elasticity in bending is presented in Table VI.

As seen from Table VI, the effects of variance sources (wood material, impregnation method, and their interaction) on the modulus of elasticity in bending were found to be significant ($P < 0.01$). The comparisons of the mean values of 24 treatment groups as the result of Duncan's multiple range test are shown in Table VII.

According to Duncan's multiple range test results, within the nonimpregnated wood materials, modulus of elasticity in bending was found to be the highest in Oriental beech (12,490 N mm^{-2}) and the lowest in poplar (5449 N mm^{-2}). Among the impregnated wood materials, the highest modulus of elasticity in bending was obtained in Oriental beech samples (10,720 N mm^{-2}) for short-term dipping method, whereas the lowest was obtained in poplar samples (4597 N mm^{-2}) for long-term dipping method. The modulus of elasticity in bending determined with regard to the wood materials and impregnation periods is given in Figure 2.

For the impregnation with I-Aqua, the modulus of elasticity in bending decreased in all wood species except for Scotch pine with the increase in the impregnation period. However, in Scotch pine, the modulus of elasticity increased with the increase in the impregnation period.

TABLE VI
ANOVA Indicating the Impacts of Wood Material and Impregnation Period on the Modulus of Elasticity in Bending

Source	Degrees of freedom	Sum of squares	Mean square	F value
Factor A[a]	5	1,079,105,504.570	215,821,100.914	2433.8473*
Factor B[b]	3	44,976,405.364	14,992,135.121	169.0686*
AB	15	75,244,739.908	5,016,315.994	56.5698*
Error	240	21,281,969.153	88,674.871	
Total	263	1,220,608,618.995		

[a] A, wood materials.
[b] B, Impregnation period.
* $P < 0.01$.

TABLE VII
Average Comparisons of Modulus of Elasticity in Bending ($N\ mm^{-2}$)

Treatments	Modulus of elasticity*
I + C	12,490 a
II + C	11,800 b
I + S	10,720 c
III + L	10,400 d
II + S	10,380 d
III + M	10,090 e
II + M	10,030 e
I + M	9,960 e
I + L	9,660 f
III + S	9,377 g
II + L	9,239 gh
III + C	9,042 h
V + C	8,172 i
V + S	7,616 j
IV + C	7,601 j
IV + M	7,485 j
V + M	7,457 j
IV + S	7,410 jk
V + L	7,160 k
IV + L	6,656 l
VI + C	5,449 m
VI + S	4,985 n
VI + M	4,875 n
VI + L	4,597 o

* Different letters in the columns refer to significant changes among wood types at 0.05 confidence level ($LSD_{0.5}$ = 513.5). I: Oriental Beech, II: Oak, III: Scotch pine, IV: Uludag Fir, V: Oriental Spruce, VI: Poplar, C: Control, S: Short-term dipping, M: Medium-term dipping, L: Long-term dipping.

DISCUSSION

The air-dry and full-dry densities of impregnated samples increased with respect to control samples. It is probably due to more penetration of impregnation solution into the wood with the extension of time. As a matter of fact, it was observed that the retention amount was higher in long-term dipping than in short-term dipping. In a similar research, it was reported that in the impregnation of Scotch pine and Oriental beech the retention increased with the increase in the impregnation period.[22]

The amount of retention in the long-term dipping of Oriental beech, oak, Scotch pine, Uludağ fir, Oriental spruce, and poplar were found to be higher than those in medium- and short-term dipping. On the other hand, the amount of retention was observed as sufficient in Scotch pine as but higher than expected in Oriental beech. The lowest retention amount was found in Scotch pine and oak. It can be a result of pit aspiration in Scotch pine and tyloses in oak.

Among the nonimpregnated wood materials, the highest modulus of elasticity in bending was obtained in Oriental beech and control samples. The modulus of elasticity in bending at this situation from the highest to the lowest can be enumerated as Oriental beech, oak, Scotch pine, Uludağ fir, Oriental spruce, and poplar. With regard to the impregnation period, the sequence from the highest to the lowest was short-term, medium–term, and long-term dipping.

Higher modulus of elasticity values were observed in the samples impregnated with Imersol Aqua by short-term dipping method. Accordingly, it can be pointed out that, except for Scotch pine, the modulus of elasticity in bending increased with the increase in the retention amount of the impregnation material.

In the interaction of wood material and impregnation period, the highest modulus of elasticity values were found in the samples impregnated with short-

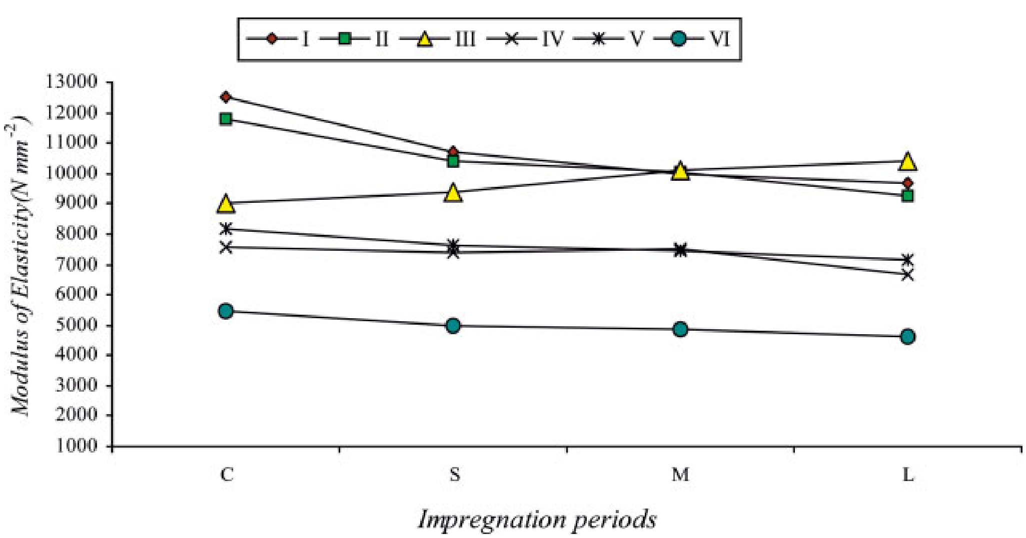

Figure 2 Modulus of elasticity in bending in relation to wood species and impregnation periods (I: Oriental beech, II: oak, III: Scotch pine, IV: Uludağ Fir, V: Oriental spruce, VI: Poplar, C: Control, S: Short-term dipping, M: Medium-term dipping, L: Long-term dipping). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

term dipping method except for Scotch pine, whereas the lowest were in the samples impregnated with long-term dipping method. It is probably due to the negative effects of I-AQUA on the structure of the wood material. As a matter of fact, the modulus of elasticity values decreased with the increase in the impregnation period. The only exclusion for this approach was the samples of Scotch pine. For Scotch pine samples, the modulus of elasticity increased with the increase in the impregnation period. This situation can be attributable to the higher resistance of Scotch pine against the chemical substances. It was reported that the needle-leaved woods, having less hemicellulose, are more resistant to chemical effects than are broad-leaved woods.[23]

In consequence, in massive constructions and furniture elements where the modulus of elasticity in bending after impregnation is of great concern, short-term impregnation of Oriental beech and Scotch pine materials could be recommended.

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