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Effects of geothermal hot water treatment on rate of water absorption, modulus of elasticity, compressive strength parallel to grain of Brutian pine wood: A case study from Sakarya, Turkey

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Abstract: The aim of this study is to investigate the effects of different geothermal hot waters on some properties of Turkish red pine (*P. brutia* Ten.) sapwood samples. The geothermal waters were taken from the geothermal resources which are Kuzuluk, Geyve and Taraklı of Sakarya region in Turkey. The treatment fluids with four different temperature (23ºC, 48ºC, 69ºC, 92ºC) were prepared (±2 degrees of precision) for each geothermal resource. After the wood samples were separately impregnated with these liquids using the thermic method, the properties (rate of water absorption, modulus of elasticity, compression strength parallel to grain) of these samples were tested. Findings obtained from the tests were evaluated separately statistically for each properties. As a result, while geothermal treatments did't make a meaningful contribution to modulus of elasticity of the red pine wood, they influenced the rate of water absorption and compression strength parallel to grain properties significantly. For rate of water absorption, the highest value (79.10%) was found in Kuzuluk 92°C treatmen but the least value (58.10%) was obtained in Geyve 48°C treatment. For three different geothermal sources, it was seen that the compression strength parallel to grain decreased significantly compared to the control (untreated) samples.
Keywords: Geothermal, Impregnation, Wood properties, Sakarya

Jeotermal sıcak su muamelesinin kızılçam odununda su alma oranı, elastikiyet modülü ve liflere paralel basınç direnci üzerine etkisi: Sakarya yöresinden bir örnek çalışma

Özet: Bu çalışmanın amacı farklı sıcaklıklı jeotermal suların kızılçam (*P. brutia* Ten.) diri odununda bazı özellikler üzerine etkilerini araştırmaktır. Jeotermal sular Sakarya bölgesi Kuzuluk, Geyve ve Taraklı jeotermal kaynaklarından alınmıştır. Her jeotermal kaynak için ± 2ºC hassasiyetle 23ºC, 48ºC, 69ºC ve 92ºC olmak üzere dört farklı sıcaklıkta jeotermal sıvılar hazırlanmıştır. Termik yöntem kullanılarak bu sıvılarla ayrı ayrı muamele edilen odun örneklerinin su alma oranı, elastikiyet modülü ve liflere paralel basınç direnci özellikleri test edilmiştir. Testlerden elde edilen bulgular, her özellik için istatistiksel olarak ayrı ayrı değerlendirilmiştir. Sonuç olarak, jeotermal sıcak su muamelesi kızılçam diri odununun elastikiyet modülü üzerine anlamlı bir etki yapmazken, su alma oranı ve liflere paralel basınç direnci üzerinde önemli derecede etkili olmuştur. Su alma oranı için, en yüksek değer (%79.10) Kuzuluk 92°C muamelesinde bulunurken, en düşük değer (%58.10) Geyve 48°C muamelesinde elde edilmiştir. Üç farklı jeotermal kaynak için, liflere paralel basınç direncinin, muamele edilmemiş kontrol örneklerine kıyasla önemli ölçüde azaldığı görülmüştür.
Anahtar kelimeler: Jeotermal, Emprenye, Odun özellikleri, Sakarya

1. Introduction

Wood is a natural material that is also using outdoors. The most important goals are increasing strength, stability and providing long-term benefits. In order to achieve these, further studies have been carried out to reduce the factors that can damage the wood, because it can cause huge financial losses due to harmful factors in the environment.

Impregnation is necessary to prevent destruction of harms and provide stable construction on the wood. It was reported that the traditional impregnation process has extended the life of wood by 5-10 times because of the usage of chemicals (Aytaşkın, 2009).

It was also reported that the impregnation of wood have become more harmless, renewable and natural for human health owing to chemicals up to now (Bozkurt et al., 1993). It can be said that these approaches are caused by the environmental pollution and health problems on human that has happened all over the world.

Geothermal fluids are pure, more reliable, natural and friendly resource among other sources while studies are increasing on geothermal energy in the World (URL, 2015). Although the negative effects of chemicals such as acidic, alkaline and salty materials in geothermal waters are especially mentioned in agricultural areas, but they can be compensated with less cost compared to other raw materials (Şamilgil, 1986).

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Besides, Turkey has abundant geothermal sources, because it occupies an active tectonic belt in geological and geographical location. Turkey has also the seventh largest geothermal potential in the world and the second largest source of geothermal energy after Italy in Europe (Arslan et al., 2001). It is stated that 12% of Turkish geothermal waters are high (100-280^{0}C) and 88% are low and medium temperature (Akkuş and Alan, 2016). This state results in the usage of geothermal energy resources in different industries.

At the same time, geothermal sources has mostly been used as residential and greenhouse heating and electric energy production in Turkey (URL, 2015). Because of the geological structure of the country, these sources are more concentrated in Western Anatolia and Aegean Regions than others (Koçak, 2005). It was reported by a number of researches in the literature studies that on the impregnation of wood materials with geothermal fluids and their use in the forest products industry (Dağdaş, 2007; Var, 2009). Through the vapor produced from geothermal sources at 120^{0}C can be utilized for paper making (drying, heating, etc.) (Dağdaş, 2007).

Nevertheless, the forest industry has an important potential to meet energy, hot water and chemical requirements when Turkey's geothermal resources are examined. A number of researchers have already reported that the geothermal fluid is highly dissolved in the presence of Na, Ca, Mg,Cl^-, N,H, HCO_3^-, H_2S , $SO_{4-2,}$ $SiO_{2,}$ NH_3 , CO_2, CH_4, K, F^- , Fe, B compounds (Var, 2009, Lund et al., 1978, Mahon et al., 2000, Yeşin, 2003, Tarcan, 2003, Tarcan, 2005, , Mutlu, 2004).

In this study, Sakarya province geothermal resources were examined for impregnation of red pine sapwood in the low and medium temperatures. Because, Sakarya represents 17 geothermal resources in Western Anatolia and Aegean Regions, and these resources have plenty of chemical substances and mineral salt types. It was reported that its water contains high concentration of B, Na, Ca, K, Cl, CO_3 elements (Barut and Erdoğan, 2011). However, Kuzuluk, Taraklı and Geyve geothermal areas well known and active geothermals in the province. On the other hand, temperatures, chemical substances, mineral salts and economics of geothermal resources have been investigated by Arslan et al. It has reported that Kuzuluk source has geothermal temperature range (60^{0}C-84^{0}C), thermal power (56.5 MWt) and flow (293 L / s) (Arslan et al., 2001; Akkuş et al., 2016; Barut and Erdoğan, 2011).

However, there were not any studies on determining the properties of red pine wood materials of these resources. These sources may be suitable source for wood impregnation and also may be contribute to some practical properties of the wood. In this study, it was aimed to investigate the effects on some properties of red pine wood of Kuzuluk, Taraklı and Geyve geothermal resources from Sakarya region of Turkey. In this sense, the effects on rate of water absorpsion, modulus of elasticity and compression strength parallel to grain of wood material were investigated.

2. Material and methods

2.1. Material

In this investigation, it was utilized three different geothermal resources waters located in Sakarya region of Turkey and the sapwood samples of Turkish red pine (*Pinus brutia* Ten.). Also, distilled water was used to compare the effects of geothermal waters on properties of wood samples.

First of all, the geothermal waters were collected in hot state from Kuzuluk, Taraklı and Geyve district geothermal sources of Sakarya province and filled in special containers. After that geothermal waters moved to the laboratory, the geothermal treatment liquids which used in impregnation studies were prepared with sensitivity of ± 2^{0}C. For each geothermal resource, the treatment liquids were prepared in four different temperature (23^{0}C, 48^{0}C, 69^{0}C, 92^{0}C).

The wood specimens were taken radially from the sapwood side of the red pine logs, in various sizes, robust, smooth, fibrous and non-knitted lattices (TS 345, 2012; ISO 4471, 1982). For this purpose, according to ISO 3129 (1975), test and control groups were prepared from the wood samples air-dried after the planing machine (ISO 3129, 1975). The samples were prepared 3x3x1.5 cm for rate of water absorpsion tests, 2x2x30 cm for modulus of elasticity tests and 2x2x10 cm for compression strength parallel to grain tests. The samples were conditioned up to air dryness humidity, and weighed with precision of ± 0.01. These samples were dried up to the full dry weight at 103± 2°C in a drier, and cooled up to the normal room temperature in the desiccator, and weighed again with the same precision (ISO 3130, 1975). Thus, the sizes of the samples were determined with air dry and full dry weights. For each test, after all samples were measured in this manner they were stored in locked nylon bags until they were treated with geothermal fluids.

2.2. Method

Impregnating process was carried out in the laboratory under standart conditions (TS EN 47, 2016). The hot-cold immersion method (thermic method) was used for the impregnation experiments (TS 343, 2012). The wood samples were immersed in geothermal hot waters for 6 hours before immersed in geothermal cold waters for 2 hours, and then lightly dried with a paper. According to ASTM D1413-07e1 (2007), all samples were impregnated separately with four different geothermal hot waters from three different geothermal sources for following tests.

Rate of Water Absorption test was conducted in accordance with ASTM D570 (2010). For each sample, the absorption value was calculated by the following equation, where *RWA* is the rate of water absorption (%); A_w is the wet weight after water immersion (g); A_0 is the full dry weight (g) before the water immersion.

$$RWA=[(A_w - A_0)/A_0]x100 \quad (1)$$

Modulus of Elasticity test was carried out in accordance with ISO 3349 (1975). For each sample, the modulus of elasticity value was calculated by the following equation, where *MOE* is the modulus of elasticity in bending (N/mm^2); *P* is the average of the loads below the elastic limits (*N*); *L* is the distance between the centers of supports (mm); *f* is the averages of deflections between elastic bounds (mm); *b* and *h* are the width and thickness (mm) of the test pieces, respectively.

$$MOE=(PxL^3)/(4xbxfxh^3)1 \quad (2)$$

Compression Strength Parallel To Grain Test was carried out in accordance with ISO 3787 (1976). For each sample, the value of compression strength parallel to grain the equation was calculated by the following equation, where *CSPG* is compression strength parallel to grain (N/mm^2); P_{max} is the maximum load (N); *b* and *h* are width and thickness (mm) of the test pieces, respectively.

$$CSPG=P_{max}/(bxh) \quad (3)$$

Statistical analysis values were obtained statistically with 95% confidence by analysis of variance (ANOVA) and Duncan tests. For this purpose, according to the geothermal resource type, the effects were found on these properties after the descriptive statistics. Then, the homogeneity groups were investigated for the factors which have significant effects. After that, the averages were compared for differences. All statistical values were calculated in the SPSS software program.

3. Results and discussion

Rate of Water Absorption Test results (ANOVA and Duncan) and descriptive statistics were given in Table 1 and 2, respectively. The RWA graph was also shown in Figure 1. According to these results, while Kuzuluk 92^{0}C treatment has the highest RWA (79.10%) compared with the untreated control samples, Geyve 48^{0}C treatment has the least effect on RWA (58.10%). Possible rank is Kuzuluk 92^{0}C > Geyve 92^{0}C > Geyve 48^{0}C.

Geothermal resources have significant effect on the RWA for red pine wood (ANOVA, Table 2). Duncan test was performed to see the differences between these effects. Even if the temperature of geothermal waters increased to 92^{0}C, there was not significant difference between the untreated control sample with all geothermal resources on the RWA.

However, the chemicals (CBC and phosphoric acid) reduced water absorption compared to the untreated control sample, but borax with boric acid increased water absorption (Baysal et al., 2004). In this study, the increase on RWA of the Kuzuluk geothermal source can be attributed to the excess of boron mineral (Figure 1).

Table 1. Descriptive statistics for RWA in red pine wood impregnated with different temperature geothermal waters

	Geothermal		Descriptive statistics			
	Resource type	Water temperature (^{0}C)	Average	Standard deviation	Least	Most
RWA (%)	Geyve	23	59.26	1.381	56.63	61.02
		48	58.10	2.576	54.17	62.67
		69	63.33	2.651	59.74	68.15
		92	71.05	2.849	67.44	76.01
	Kuzuluk	23	59.50	2.125	56.46	64.40
		48	66.78	2.255	63.96	72.22
		69	67.69	2.165	64.74	71.67
		92	79.10	3.458	73.27	83.05
	Taraklı	23	60.87	1.729	57.78	64.32
		48	59.04	2.254	55.21	61.84
		69	63.35	3.274	59.44	68.43
		92	66.65	9.318	44.18	78.19
	Control	-	69.50	15.213	43.46	99.68

Table 2. ANOVA and Duncan's test results for the effect of geothermal water temperature on RWA of red pine wood

Geothermal resource	ANOVA results						Duncan's test results	
	Variance source	SOS	DOF	AOS	F	P	GWT (^{0}C)	RWA (%)*
Geyve	Between groups	1372.125	4	343.031	6.723	0.000	23	59.26 a
	Inside groups	2296.081	45	51.024			48	58.10 a
	Total	3668.206	49				69	63.33 a,b
							92	71.05 c
Kuzuluk	Between groups	1374.601	4	343.650	6.768	0.000	23	59.50 a
	Inside groups	2284.626	45	50.769			48	66.78 b
	Total	3659.227	49				69	67.69 b
							92	79.10 c
Taraklı	Between groups	718.261	4	179.565	2.664	0.044	23	60.87 a
	Inside groups	3033.388	45	67.409			48	59.04 a
	Total	3751.648	49				69	63.35 a,b
							92	66.65 a,b
Control							-	69.50 b,c

SOS: Sum of squares. DOF: Degree of freedom. AOS: Averages of squares. F: F-Value. P: Level of significance. GWT: Geothermal water temperature. *: The same letters in each column indicates that there is no significantly difference ($P < 0.05$) between the means.

Modulus of Elasticity Test results (ANOVA and Duncan) and the descriptive statistics were given in Table 3 and 4, respectively. Also, the MOE graph was shown in Figure 2. The values of MOE reduced for Geyve (48 ^{0}C) and Kuzuluk (48 ^{0}C, 69 ^{0}C, 92 ^{0}C) treatments compared with the untreated control samples (6307.063 N/mm^2) but increased for other treatments. The maximum increase can be expressed by Geyve 23 ^{0}C treatment (11304.613 N/mm^2). It was seen that the Taraklı geothermal source provides more MOE than the untreated control samples (Table 3).

According to the Table 4, there was'nt statistically significant effect in 95% confidence level on the MOE of red pine wood for Geyve geothermal, $p>0.05$ (0.342), and for Kuzuluk geothermal, $p>0.05$ (0.147). But the effect of Taraklı geothermal was statistically significant, $p<0.05$ (0.000). Furthermore, all of the geothermal water temperatures were found to be in different homogeneity groups. The geothermal water temperatures affected the MOE negatively but did'nt make significant differences on some values compared with the untreated control samples.

However, when a number of findings of MOE were compared with the literatüre (Bozkurt et al., 1993; Karademir, 2012; Young, 2013; Öktem and Sözen, 2014; Demirtas, 2015), it was seen that these values varied between 5128.43 N/mm^2 whit 11304.61 N/mm^2, and found different from the literatüre. This difference may be due to the chemical composition and temperature of the geothermal waters.

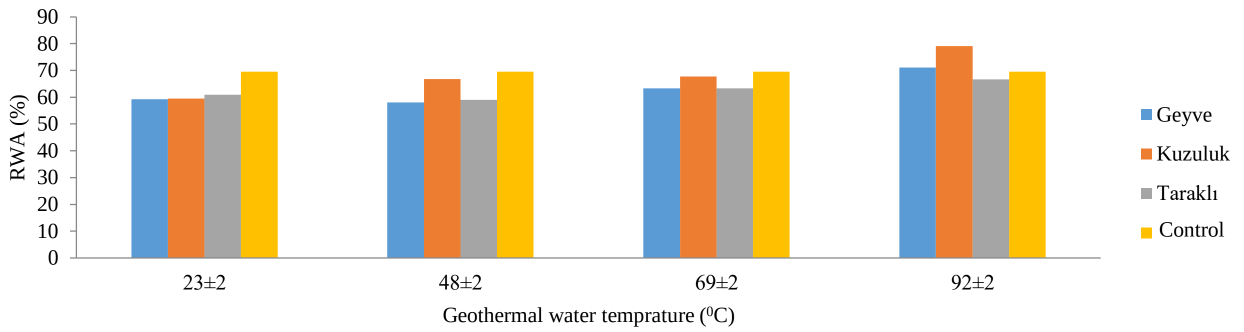

Figure 1. The RWA graph for geothermal water temperature

Table 3. Descriptive statistics for MOE in red pine wood impregnated with different temperature geothermal waters

	Geothermal		Descriptive statistics			
	Source type	Water temprature (^{0}C)	Average	Standard deviation	Least	Most
MOE (N/mm^2)	Geyve	23	11304.61	15610.204	4833.61	55577.19
		48	5312.47	1050.144	4033.09	7127.86
		69	9623.95	2044.512	7023.18	13064.00
		92	8773.36	1370.631	6410.29	10330.24
	Kuzuluk	23	6789.14	1479.797	4882.36	9194.09
		48	5966.13	885.450	4644.77	7821.23
		69	5128.43	812.733	3899.57	6261.73
		92	5477.35	1227.348	3197.13	6968.75
	Taraklı	23	10631.86	1297.533	8667.59	13321.48
		48	9732.63	2001.622	6040.83	12236.06
		69	10922.14	2272.893	6106.38	13724.74
		92	6881.59	2594.771	4038.17	11132.14
	Control	-	6307.06	2631.963	259.44	9953.65

Table 4. ANOVA and Duncan's test results for the effect of geothermal water temperature on MOE of red pine wood

Geothermal resource	ANOVA results						Duncan's test results	
	Variance source	SOS	DOF	AOS	F	P	GWT (^{0}C)	MOE (N/mm^2)*
Geyve	Between groups	238953495.886	4	59738374.0	1.159	0.342	23	11304.61 a
	Inside groups	2319904557.26	45	51553434.6			48	5312.47 a
	Total	2558858053.15	49				69	9623.95 a
							92	8773.36 a
Kuzuluk	Between groups	17289414.974	4	4322353.74	1.791	0.147	23	6789.14 b
	Inside groups	108611687.105	45	2413593.05			48	5966.13 a,b
	Total	125901102.079	49				69	5128.43 a
							92	5477.35 a,b
Taraklı	Between groups	185788471.291	4	46447117.8	9.473	0.000	23	10631.86 b
	Inside groups	220645733.506	45	4903238.52			48	9732.63 b
	Total	406434204.797	49				69	10922.14 b
							92	6881.59 a
Control							-	6307.06 a,b

SOS: Sum of squares. DOF: Degree of freedom. AOS: Averages of squares. F: F-Value. P: Level of significance. GWT: Geothermal water temperature. *: The same letters in each column indicates that there is no significantly difference ($P < 0.05$) between the means.

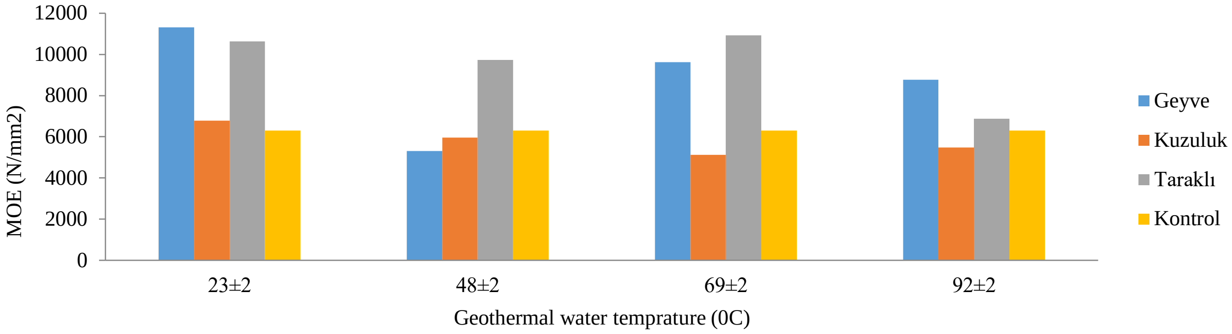

Figure 2. The MOE graph for geothermal water temperature

Compression Strength Parallel To Grain Test results (ANOVA and Duncan) and the descriptive statistics were listened in Table 5 and 6, respectively. The CSPG graph was also given in Figure 3. The values of CSPG decreased compared with the control samples for all geothermal resources (Table 5). When the geothermal water temperature increased, the CSPG decreased (Figure 3). The the highest value (64.07 N/mm^2) of the CSPG were found on the Kuzuluk 23^{0}C treatment and the least value (31.29 N/mm^2) on the Geyve 92^{0}C treatment.

According to the results of Table 6, it was seen that the geothermal water temperature has an effect on the CSPG of red pine wood in 95% statistical confidence level. When Table 6 was examined, it was seen that there was five different homogeneous groups (A, B, C, D, E). The least effective group is A and the most effective group is B in these groups. The control samples were collected in D and E homogenous groups. Geyve 23^{0}C, Kuzuluk 23^{0}C and Tarakli 23^{0}C treatments shared the same group meanwhile Geyve 69^{0}C, Kuzuluk 48^{0}C and Taraklı 69^{0}C treatments took place in the same group. The geothermal water temperatures have an effect on the CSPG, and it may be that the possible rank is Kuzuluk 23^{0}C > Geyve 23^{0}C> Taraklı 23^{0}C.

When the CSPG findings were compared with similar studies (Bozkurt et al., 1993; Karademir, 2012; Young, 2013; Öktem and Sözen, 2014; Demirtaş, 2015), it can be said that the CSPG values changed between 31.29 N/mm^2 with 64.07 N/mm^2, and these values were compatible with the literature results.

Table 5. Descriptive statistics for CSPG in red pine wood impregnated with different temperature geothermal waters

	Geothermal		Descriptive statistics			
	Source type	Water temprature (^{0}C)	Average	Standard deviation	Least	Most
CSPG (N/mm^2)	Geyve	23	61.70	5.967	50.51	69.10
		48	55.32	8.214	37.60	65.94
		69	47.76	8.094	30.06	57.58
		92	31.29	3.356	26.19	36.14
	Kuzuluk	23	64.07	6.768	55.64	75.66
		48	51.58	5.362	45.68	62.83
		69	60.64	5.502	53.36	70.37
		92	43.20	4.672	34.11	48.35
	Taraklı	23	59.29	5.405	51.08	68.49
		48	53.95	5.218	47.11	64.02
		69	46.60	4.465	38.36	53.60
		92	38.88	6.004	30.43	49.47
Control		-	68.68	7.092	54.81	77.10

Table 6. ANOVA and Duncan's test results for the effect of geothermal water temperature on CSPG of red pine wood

Geothermal resource	ANOVA results						Duncan's test results	
	Variance source	SOS	DOF	AOS	F	P	GWT (^{0}C)	CSPG (N/mm^2)*
Geyve	Between groups	8256.491	4	2064.123	44.846	0.000	23	61.70 d
	Inside groups	2071.196	45	46.027			48	55.32 c
	Total	10327.688	49				69	47.76 b
							92	31.29 a
Kuzuluk	Between groups	4175.873	4	1043.968	29.500	0.000	23	64.07 c, d
	Inside groups	1592.477	45	35.388			48	51.58 b
	Total	5768.350	49				69	60.64 c
							92	43.20 a
Taraklı	Between groups	5254.869	4	1313.717	40.368	0.000	23	59.29 d
	Inside groups	1464.459	45	32.544			48	53.95 c
	Total	6719.328	49				69	46.60 b
							92	38.88 a
Control							-	68.68 d, e

SOS: Sum of squares. DOF: Degree of freedom. AOS: Averages of squares. F: F-Value. P: Level of significance. GWT: Geothermal water temperature. *: The same letters in each column indicates that there is no significantly difference (P < 0.05) between the means.

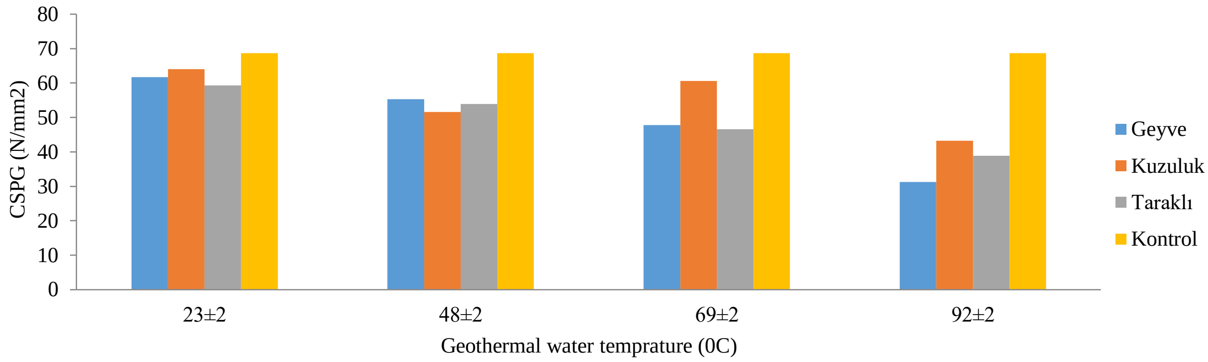

Figure 3. The CSPG graph for geothermal water temperature

4. Conclusions

According to the results of this study, the geothermal resource type effected significantly on the RWA and the CSPG of Turkish red pine sapwood but there was not significant effect on the MOE. While the geothermal hot water treatments increased the values of RWA and CSPG significantly of the red pine sapwood, the values of MOE decreased. The geothermal waters didn’t make a significant contribution to the MOE of the pine wood but they affected other properties considerably.

This study revealed that the values of RWA, MOE and CSPG were changed depending on the geothermal water temperature. The highest RWA was found in Kuzuluk 92°C treatment and the least RWA was obtained in Geyve 48°C treatment. Moreover, Geyve 23°C treatment gave the biggest MOE value while the smallest value was found with Kuzuluk 69°C treatment. For these two treatments, the MOE values were 11304.61 (N/mm^2) and 5128.43 (N/mm^2), respectively.

In summary, the sapwood materials of Turkish red pine exposed to such treatments can be used in utilizations under the effects of water (or humidity), bending and pressure for short-term periods.

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