

Full Length Research Paper

Combustion properties of wood impregnated with commercial fertilizers

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The objective of this study was to determine some combustion properties of Calabrian pine (*Pinus brutia* Ten.) wood specimens impregnated with aqueous solutions of commercial fertilizers. Ammonium sulphate (AS) and diammonium phosphate (DAP) were used as commercial fertilizers. Diammonium phosphate and ammonium sulphate fertilizers were impregnated into wood at 10, 20, and 30% concentrations prior to combustion test. Then, combustion test method containing flame source, without flame source and glowing stages was performed according to the ASTM E 160-50. Results indicate that fertilizer treatments improved the combustion properties of Calabrian pine specimens. In terms of mass loss, duration of without flame, and glowing stages as well as and the destruction time, Calabrian pine specimens impregnated with 30% DAP gave the best results. Higher concentration levels of fertilizers resulted in better combustion properties of wood.

Key words: Calabrian pine, ammonium sulphate, diammonium phosphate, combustion properties, commercial fertilizers.

INTRODUCTION

Wood and wood-based materials consist of organic compounds and are composed mainly of carbon and hydrogen; for this reason, they are combustible (Kollmann and Cote, 1968). For wood ignition, an oxygen flame source and flammable material are necessary. The combustibility of the wood is favorable when it is used as a fuel, but unfavorable as a building material. It is impossible to make wood incombustible but it is possible to make it fire retardant (Ching-Mu and Wang, 1991; Nussbaum, 1988; Ellis and Rowell, 1989; Mitchell, 1993). Wood has excellent natural fire resistance as a result of its remarkably low thermal conductivity and the fact that wood char is formed when wood is burned. In order to reduce flammability and provide safety, wood is treated with fire-retardant chemicals. In other words, the combustibility of wood may be reduced with flame-retardant or fire-retardant materials (Nussbaum, 1988; Ellis and Rowell, 1989; Mitchell, 1993). The most com-

monly used fire retardant chemicals in the wood industry are inorganic salts and include ammonium and diammonium phosphate, ammonium chloride, ammonium sulfate, borax, boric acid, phosphoric acid, and zinc chloride (Woo and Schniewind, 1987). Fire-retardant chemicals drastically reduce the rate at which flames travel across the wood surface, thereby reducing the capacity of the wood to contribute to a fire (LeVan and Tran, 1990; LeVan and Winandy, 1990). Several theories have been reviewed about fire retardant's mechanisms by Browne (1958) and LeVan (1984). The most widely accepted mechanism is referred to as the chemical theory.

This theory suggests that the fire retardants directly alter the pyrolysis of wood, increasing the amount of char and reducing the amount of volatile, combustible vapors. Baysal (1994) noted that the mass loss of Calabrian pine and Oriental beech wood treated with boric acid and borax mixture were decreased compared to untreated wood specimens. Ozcifici et al. (2007) studied the fire properties of laminated veneer lumber (LVL) prepared from beech (*Fagus orientalis* Lipsky) veneers treated with some fire retardants. They found

Abbreviations: AS, Ammonium sulphate; DAP, diammonium phosphate.

Table 1. Chemical composition of ammonium sulphate (AS) and diammonium phosphate (DAP) commercial fertilizers.

Fertilizer	Nitrogen (%)	Hydrogen (%)	Sulphur (%)	Phosphate (%)	Oxygen (%)	Pure (%)
AS	20.15	5.75	23.30	-	46.06	95
DAP	18.03	5.15	-	19.96	41.21	85

that the lowest temperature and mass loss were obtained for specimens treated with diammonium phosphate and boric acid–borax mixture. Shafizadeh (1984) studied 21 different fire retardants; phosphoric acid was the most effective in reducing the amount of volatiles and increasing the amount of residual char, followed by mono and diammonium phosphate, and zinc chloride. Lee and Kim (1982) investigated fire resistance of meranti plywoods impregnated with some fire retardant chemicals. They found that diammonium phosphate ranked the greatest in fire-retardant effectiveness.

This study was aimed to determine some combustion properties of Calabrian pine impregnated with aqueous solutions of AS and DAP commercial fertilizers.

MATERIALS AND METHODS

Preparation of test specimens and chemicals

Calabrian pine (*Pinus brutia* Ten.) specimens measuring 13 (tangential) x 13 (radial) x 76 (longitudinal) mm were prepared from air-dried sapwood of Calabrian pine (*Pinus brutia* Ten.) for combustion test. Aqueous solutions of diammonium phosphate (DAP) and ammonium sulphate (AS) fertilizers were dissolved in distilled water to concentrations of 10, 20, and 30%. Commercial fertilizers were supplied by commercial firm. Chemical compositions of AS and DAP fertilizers are given in Table 1. Wood specimens were oven dried at 103±2°C before and after treatment.

Impregnation method

Wood specimens were impregnated with aqueous solutions of fertilizers according to ASTM D 1413-76 (1976). Treatment solutions were prepared the day before the impregnation for homogenizing. A vacuum desiccator used for the impregnation process was connected to a vacuum pump through a vacuum trap. Vacuum was applied for 60 min at 760 mmHg⁻¹ before supplying the solution into the chamber followed by another 60 min at 760 mmHg⁻¹ diffusion period under vacuum. Retention was calculated from the following equation:

$$\text{Retention (kg/m}^3\text{)} = (G \times C / V) \times 10 \quad (1)$$

Where, G is the amount of solution absorbed by wood that is calculated by $T_2 - T_1$; T_2 is the weight of wood after impregnation (g); T_1 is the weight of wood before impregnation (g); C is the solution concentration as percentage, and V is the volume of the specimen as cm³.

Combustion test method

Combustion test of Calabrian pine wood specimens was determined according to ASTM E160-50 (1975). Specimens were

conditioned at 27±2°C and 30 to 35% relative humidity to the targeted equilibrium moisture content of 7% prior to fire test. Twenty four specimens were stored to make 12 layers which formed a square prism (Figure 1). The heating flame was derived from a LPG tank controlled by a sensitive bargauged valve. The flame was balanced to the standard height before fire test samples' frame. The combustion test method was performed subsequently (flame stage, without flame stage (flameless), and glowing stage) according to ASTM E 160- 50. Flame stage was finished after 180 s. The mass losses of test specimens after combustion test were calculated from the following equation:

$$\text{Mass loss} = (W_{bf} - W_{af} / W_{bf}) \times 100 \quad (2)$$

Where, W_{bf} is the weight (g) of a wood specimen before fire test and W_{af} is the weight (g) of a wood specimen after combustion test.

Evaluations of combustion test results

Combustion test results were evaluated by a computerized statistical program composed of analysis of variance and following Duncan tests at the 95% confidence level. Statistical evaluations were made on homogeneity groups (HG), of which different letters reflected statistical significance.

RESULTS AND DISCUSSION

Mass loss

Mass losses of Calabrian pine specimens, impregnated with aqueous solutions of AS and DAP commercial fertilizers after combustion test are given in Table 2. In terms of mass loss, AS and DAP fertilizers exhibited fire-retardant effects. Wood specimens treated with aqueous solutions of AS and DAP fertilizers reduced the mass loss significantly ($p \leq 0.05$) compared to the untreated control specimens. In other words, wood became more difficult to ignite, and more oxygen was needed to burn the impregnated materials. While the highest mass loss was obtained with the untreated control specimens (92%), the lowest mass loss was with the Calabrian pine, impregnated with 30% DAP fertilizer (54%). Yalinkilic et al. (1998) found that Douglas-fir specimens treated with a mixture of BA and BX (7:3; w/w) lost approximately 58% of mass during combustion. Temiz (2000) also reported that *Alnus glutinosa* wood specimens treated with similar chemicals lost about 60% of their mass. Similarly, Baysal (2003) reported that *Fagus orientalis* wood specimens treated with a mixture of BA and BX (7:3; w/w) lost around 68% of mass during combustion. Our results were consistent with the findings of the

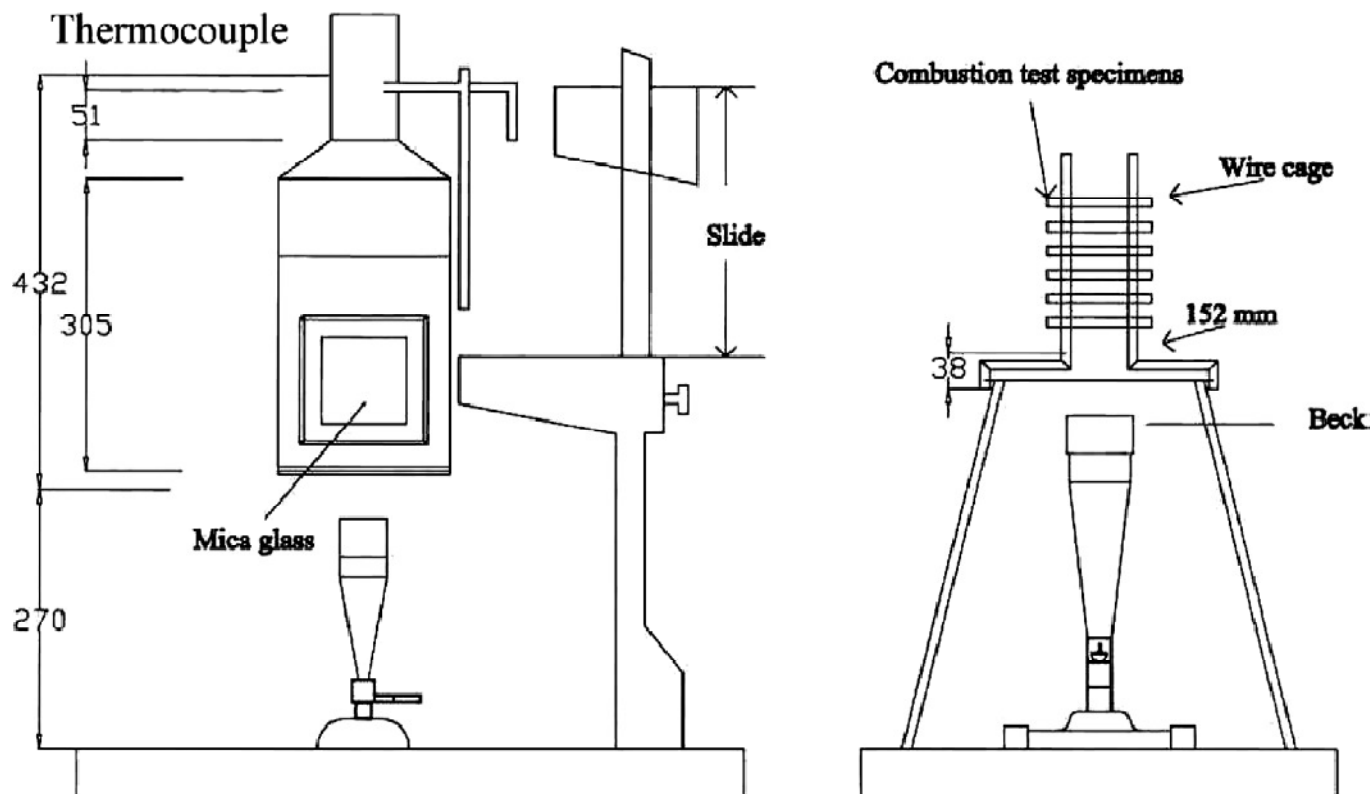


Figure 1. Combustion test apparatus.

Table 2. Mass loss of Calabrian pine after combustion test.

Fertilizer	Concentration (%)	Retention (Kg/m ³)		Mass loss (%)		
		Mean	SD	Mean ^a	SD ^b	HG ^c
Untreated	-	-	-	92.0	4.8	A
	10	14.7	3.5	75.0	6.4	BC
	20	24.1	6.7	62.0	6.3	D
AS	30	37.9	8.3	57.0	8.8	DE
	10	21.1	6.4	69.0	7.3	C
DAP	20	43.2	13.5	65.0	7.9	B
	30	68.2	11.7	54.0	9.2	E

^aThree replication were made for each group; ^bSD= Standard deviation; ^cHG = Homogeneity group.

mentioned studies. Concentration levels of AS and DAP fertilizers considering the mass losses of Calabrian pine after the combustion test are shown in Figure 2. As the concentration levels increased, the retention levels in the wood increased. Our findings showed that higher concentration levels of fertilizers resulted in lower mass loss of wood. Grexa and Lübke (2001) investigated the effect of different loads of magnesium hydroxide as a flame retardant on the flammability parameters of

particleboard. They found that increasing the amount of magnesium hydroxide significantly improved the overall fire behavior of particleboard. White (1979) noted that the oxygen index levels increased with an increase in the treatment level of chemicals. In addition, Lee (1984) reported that the rate of weight loss of *Populus alba-grandulosa* decreased as the chemical retention increased. The results of this study are consistent with these findings. Therefore, it can be concluded at this

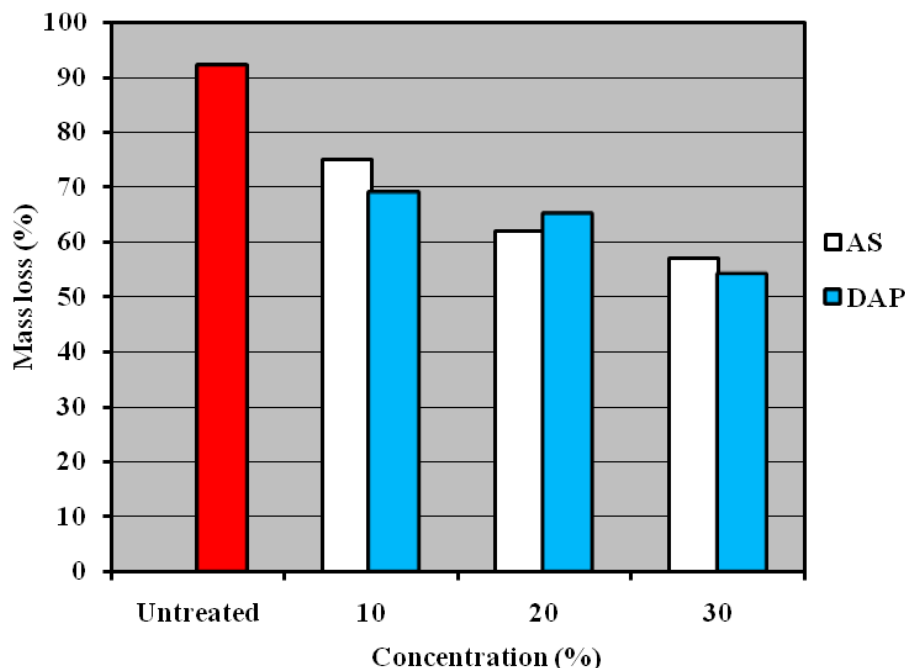


Figure 2. Concentration levels of AS and DAP fertilizers considering the mass loss of Calabrian pine.

Table 3. Duration of Calabrian pine at without flame stage (DWFS), after glowing (DGS), and to destruction.

Fertilizer	Concentration (%)	DWFS (s)			DGS (s)			Destruction(s) (mean)
		Mean ^a	SD ^b	HG ^c	Mean ^a	SD ^b	HG ^c	
Untreated	-	1535	225	A	1140	185	A	(/) 130 and (-) 390
	10	800	56	B	445	68	B	(/) 325
	20	380	48	C	390	89	BC	(/) 440
AS	30	255	39	D	324	54	D	(/) 575
	10	420	43	C	450	127	B	(/) 360
DAP	20	248	65	D	385	105	BC	(/) 680
	30	212	38	D	296	45	D	(+)

^aThree replication were made for each group; ^bSD= standard deviation; ^cHG = Homogeneity group; (/) = Partial destruction; (-) = Complete destruction; (+) = No destruction

stage that aqueous solutions of both fertilizers reduced the mass loss of Calabrian pine compared to the untreated control specimens after combustion test. Moreover, higher concentration levels of fertilizers resulted in lower mass loss of wood.

Duration of the test specimens at without flame and glowing stages and to destruction

Untreated Calabrian pine specimens gave the worst results in terms of the duration in without flame stage (DWFS) and glowing stage (DGS) as shown in Table 3.

The fertilizer treatments shortened the duration of the test specimens at without flame and glowing stages. Untreated Calabrian pine specimens had the worst result for their extended duration in, without flame stage (1535 s) and glowing stage (1140 s). In our study, Calabrian pine specimens impregnated with 30% DAP gave the best results considering the duration in without flame and glowing stages. Baysal et al. (2003, 2007) studied some combustion properties of borate-treated Calabrian pine and Douglas fir wood specimens. They reported that borate treatment shortened the duration of both wood specimens at without flame and glowing stages. Our results showed that the higher concentration levels

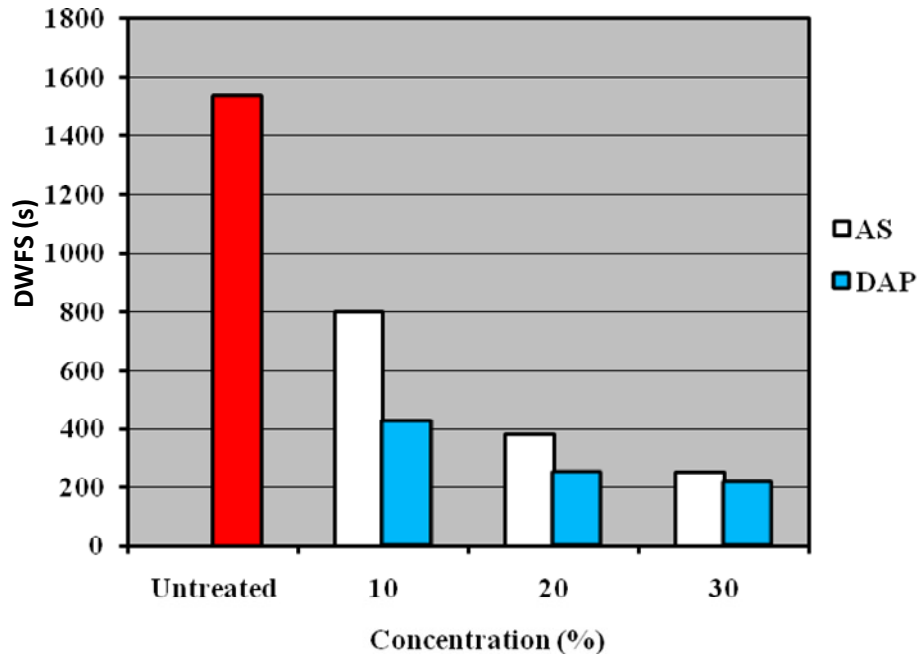


Figure 3. Concentration levels of AS and DAP fertilizers related to duration of Calabrian pine at without flame stage (DWFS).

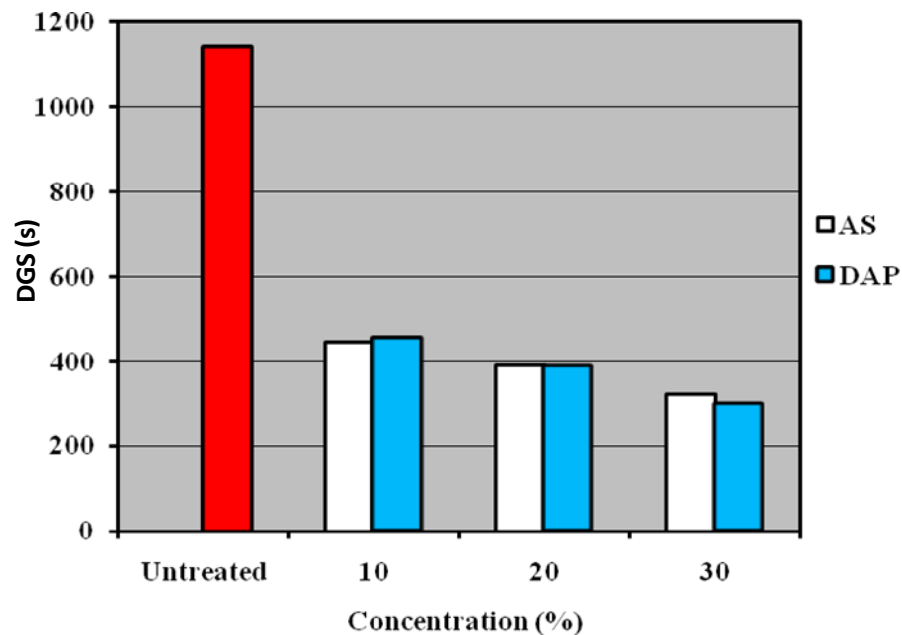


Figure 4. Concentration levels of AS and DAP fertilizers related to duration of Calabrian pine at glowing stage (DGS).

of fertilizers resulted in shorter without flame and glowing stages. Concentration levels of AS and DAP fertilizers were related to the duration of Calabrian pine at without flame and glowing stages after the fire test are given in Figures 3 and 4, respectively. Duration of destruction can be an indicator of constructional failure

during combustion or time until the beginning of constructional failure. Untreated Calabrian pine specimens gave the worst results in terms of duration of destruction. Partial (130 s) and complete destructions (390 s) were observed for untreated Calabrian pine. Our results show that Calabrian pine specimens impregnated with 30%

DAP gave the best results. Destruction was not observed in Calabrian pine specimens impregnated with 30% DAP at all combustion stages, whereas Calabrian pine specimens impregnated with other solutions of fertilizers showed partial destruction. These results are compatible with the findings of previous studies on woods impregnated with boron compounds (Baysal, 1994; Baysal et al., 2003, 2007). The higher concentration levels of fertilizers shortened the duration of the test specimens at without flame and glowing stages, thus extending the duration of destruction. Therefore, fertilizer treatments shortened the duration of test specimens at without flame and glowing stages and increased the duration of destruction.

Conclusions

Some combustion properties of Calabrian pine wood impregnated with aqueous solutions of AS and DAP commercial fertilizers were studied. Calabrian pine specimens, impregnated with 30% DAP, showed the highest fire resistance. Fertilizer treatments increased combustion properties of Calabrian pine specimens to some extent. Apparently, both fertilizers played a fire-retardant role in this study. Calabrian pine wood, impregnated with aqueous solutions of AS and DAP fertilizers, enhanced combustion parameters such as mass loss, duration of without flame and glowing stages as well as the destruction time. They caused lower mass loss, shorter duration at without flame and glowing stages as well as longer destruction time.

A large number of fire retardant chemicals have been introduced to the market. However, many of them could not gain acceptance either because of low efficacy, high cost or corrosiveness. Our results showed that the aqueous solutions of AS and DAP commercial fertilizers can be used as alternative preservatives where fire risk is high, because of their low costs and fire-retardant properties. However, ammonium sulphate (AS) as a sulphate based fire retardant chemical are corrosive and this can cause problems with plumbing, electrical, or building component equipment. According to our findings, the aqueous solutions of 30% DAP seems more appropriate when timber is to be used in such service conditions where fire risk exists.

REFERENCES

- ASTM-D 1413-76 (1976). Standard test method of testing wood preservatives by laboratory soilblock cultures. Annual Book of ASTM Standards.
- ASTM E 160-50 (1975). Standard test method for combustible properties of treated wood by the crib test.
- Baysal E (1994). Çeşitli borlu ve WR bileşiklerinin kızılçam odununun bazı fiziksel özelliklerine etkisi. M.Sc Thesis. Karadeniz Technical University, Institute Sci. Technol. Trabzon, Turkey, Turkish.
- Baysal E (2003). Yanmayı geciktirici kimyasal maddeler ve bitkisel sepi maddeleri ile muamele edilen Doğu kayını (*Fagus orientalis* Lipsky) odunun yanma özellikleri. Firat University, J. Sci. Eng. 15(1): 163-174 (in Turkish).
- Baysal E, Yalınkılıç MK, Colak M, Goktas O (2003). Combustion properties of Calabrian pine (*Pinus brutia* Ten.) wood treated with vegetable tanning extracts and boron compounds. Türk. J. Agric. For. 27(4): 245-252.
- Baysal E, Altınok M, Colak M, Ozaki SK, Tokar H (2007). Fire resistance of Douglas fir (*Pseudotsuga menziesii*) treated with borates and natural extractives. Bioresour. Technol. 98: 1101-1105.
- Browne FL (1958). Theories of the combustion of wood and its control. USDA FPL Rep., pp. 21-36. Forest Prod. Lab., Madison, WI (rewritten and reaffirmed in 1963).
- Ching-Mu T, Wang YL (1991). Incombustibility of fire-retardant-paint coated wood panels. Quart. J. Expt. Forest. 5(3): 45-60.
- Ellis WD, Rowell RM (1989). Flame-retardant treatment of wood with a diisocyanate and an oligomerphosphate. Wood Fiber Sci. 21(4): 367-375.
- Grexa O, Lübke H (2001). Flammability parameters of wood tested on a cone calorimeter. Polym. Degrad. Stabil. 74: 427-432.
- Kollmann F, Cote WA (1968). Principles of wood science and technology I. Solid wood. Springer-Verlag.
- Lee PW, Kim JM (1982). Studies on fire-retardant treatment and press drying of plywood. Kor. Wood Sci. Technol. 10(1): 5-37.
- Lee PW (1984). Studies on the residual bending strength of burned wood treated with fire-retardant chemicals Kor. Wood Sci. Technol. 12(2): 10-19.
- LeVan SL (1984). Chemistry of fire retardancy. In Rowell RM, ed. The chemistry of solid wood. Advances in Chemistry Series 207. American Chemical Society, Washington, DC.
- LeVan S, Winandy JE (1990). Effect of fire-retardant treatments on wood strength: A review. Wood Fiber Sci. 22: 113-131.
- LeVan S, Tran HC (1990). The role of boron in flame retardant treatments. Proc. of First Int. Conf. on Wood Protection with Diffusible Preservatives, Tennessee, USA., pp. 28-30. Nov 1990. pp. 39-41.
- Mitchell S (1993). Fire performance of wood: Test methods and fire retardant treatments. Proceedings of the 4th annual BCC Conference on Flame Retardancy, Stamford, CT Normwalk, CT; Business Communications Co, 18-20 May 1993. pp. 36-43.
- Nussbaum R (1988). The effect of low concentration fire retardant impregnations on wood charring rate and char yield. J. Fire Sci. 6: 290-306.
- Ozçifci A, Tokar H, Baysal E (2007). Fire properties of laminated veneer lumber treated with some fire retardants. Wood Res. 52(4): 37-46.
- Shafidzadeh F (1984). Pyrolysis and combustion. In Rowell RM, ed. The chemistry of solid wood. Advances in Chemistry Series 207. Chapter 13. American Chemical Society, Washington, DC.
- Temiz A (2000). Çeşitli kimyasal maddelerle muamele edilen Kızılağaç (*Alnus glutinosa* (L.)) odununun fiziksel ve mekanik özellikleri. MSc Thesis. Karadeniz Technical University, Institute Sci. Technol. Trabzon, Turkey Turkish.
- White RH (1979). Oxygen index evaluation of fire-retardant-treated wood. Wood Sci. 12(2): 113-121.
- Woo JK, Schniewind AP (1987). Thermal degradation of wood treated with fire retardants I. DSC analysis. Holzforschung, 41:305-313.
- Yalınkılıç MK, Baysal E, Demirci Z (1998). Çeşitli emprenye maddelerinin Douglas (*Pseudotsuga menziesii* (Mirb.) Franco) odununun yanma özellikleri üzerine etkileri. Pamukkale University, J. Eng. Sci. Turk. 4: 613-624.