# Mechanical properties of epoxidized oil heat treated Eucalyptus wood

HEJAZI Seyed Javad[1], ABEDINI Raoufeh[2], GHORBANI Maryam[3], DASTOORIAN Foroogh[4]

[1]MSc. Graduate from Sari Agricultural Sciences and Natural Resources University
[2,4]Assitant Professor in Sari Agricultural Sciences and Natural Resources University
[3] Professor in Sari Agricultural Sciences and Natural Resources University
abedini_rf@sanru.ac.ir

**Keywords:** epoxidized soybean oil; mechanical properties; bending strength; oil heat treatment; weight percent gain

## Context and objective

Wood thermal modification is one of the environmentally friendly methods to increase treated samples durability, service life and safety for burning after their service life (Nejad et al. 2019). Thermal modification of wood has been developed since the beginning of the 20th century by proving the effect of high temperature on improving dimensional stability and natural durability of wood (Sandberg et al. 2017).

The basis of thermal modification methods is the chemical change of wood under high temperature. Thermal modification occurs between 180 and 260 °C, because lower temperatures do not significantly affect wood components, and temperatures above 260 °C cause undesirable degradation (Hill 2006, Lee et al. 2018).

Improving physical properties and increasing resistance against biotic destructive factors are benefits of thermal modification, while reducing mechanical properties is one of its disadvantages (Hill 2006, Lee et al. 2018). Thermal modification take place in different mediums such as steam, Nitrogen and hot oils which results in wood with different properties. Oil heat treatment process is based on the simple method of heating wood in vegetable oils. Since the boiling point of many vegetable oils is higher than the temperature required for heat treatment of wood, thermal modification in hot oil bath is a practical option (Sandberg et al. 2017). Oil heat treatment increase hydrophobicity with two mechanisms: hydrophobing wood cell wall because of presence of non-polar oil and modifying chemical structure of wood, reduction of moisture absorption capacity by degradation of hemicellulose at high temperature. But there is no reaction between the oil and wood cell wall. However functionalized vegetable oils are able to bond with cell wall through functional groups such as epoxy. In this way other than physical properties, mechanical properties may enhance (Tjeerdsma et al. 2005, Ghasemi et al. 2023). Eucalyptus wood as a fast-growing planting species with high density can grow and adapt to different part of Iran. As thermal modification mostly accompanied with mass loss, Eucalyptus wood with high density is suitable for thermal modification. This study investigated effect of oil heat treatment with crude and epoxidized soybean oil on weight gain and mechanical properties of Eucalyptus wood.

## Material and Methods

Eucalyptus logs with approximate diameter of 40 cm and a length of 200 cm were first cut into 3 cm thick lumbers and after drying outdoor, they were cut to standards size for mechanical tests according to ASTM-D143-94. The samples were dried in an oven at a temperature of 103

°C for 24 hours. Two types of crude soybean oil and epoxy soybean oil were obtained from Sepahan Fanavran Shimi Company.

The dried samples were immersed in oils and heat treated in an oven at 150, 175 and 200 °C for 4 hours. Different treatments and brief cod of sample is shown in Tab. 1.

Tab. 1: treatments and brief cod of sample

| Temperature (°C) | 150 | 175 | 200 |
|---|---|---|---|
| Crude soybean oil | SO150 | SO175 | SO200 |
| Epoxy soybean oil | ESO150 | ESO175 | ESO200 |

Properties of modified samples were evaluated according to equation 1 to 3. For weight percent gain:

$$WPG = \frac{W_2 - W_1}{W_1} \times 100 \qquad (1)$$

WPG: weight gain (%), W1: dried weight before modification (g), W2: dried weight after modification (g)

To determine the bending strength, samples were tested in the SANTAM STM-20 machine with a deflection rate of 1.3 mm/min. Modulus of rupture (MOR) and modulus of elasticity (MOE) were calculated according to equations 2 and 3 respectively:

$$MOR = \frac{3PL}{2bh^2} \qquad (2)$$

MOR: modulus of rupture, P: maximum load, L: span length (mm), h: sample thickness (mm), b: sample width (mm).

$$MOE = \frac{P_L L^3}{4bh^3 \delta_L} \qquad (3)$$

MOE: modulus of elasticity (MPa), PL: load at proportional limit (N), b: samples width, L: span length (mm), $\delta_L$: deflection at proportional limit.

Hardness of the samples was conducted according to ASTM D143 using the SANTAM STM-20 machine by a steel ball with diameter of 11.3 mm at speed of 6 mm/min on the tangential surface to measure impact resistance, samples were tested in SANTAM SIT-100 Pendulum Impact Tester machine according to ASTM-D143 standard.

## Results and discussion

*Density and Weight percent gain (WPG) after oil heat treatment*

The highest density after thermal modification was related to crude oil at 150 °C in both oils and crude soybean oil at 175 °C (Fig. 1a). With increasing temperature the density decreased and the lowest density observed in sample modified at 200 °C with epoxy soybean oil. Research has reported that hydrothermal modification decreased the dry density of samples and some reports no significant change after hot oil modification (Abde et al. 2014, Yang and Jin 2021). In oil heat treatment, part of the oil penetrates into the wood and increases the weight of the sample and compensate mass loss caused by the destruction of the cell wall in high temperature around 175°C.

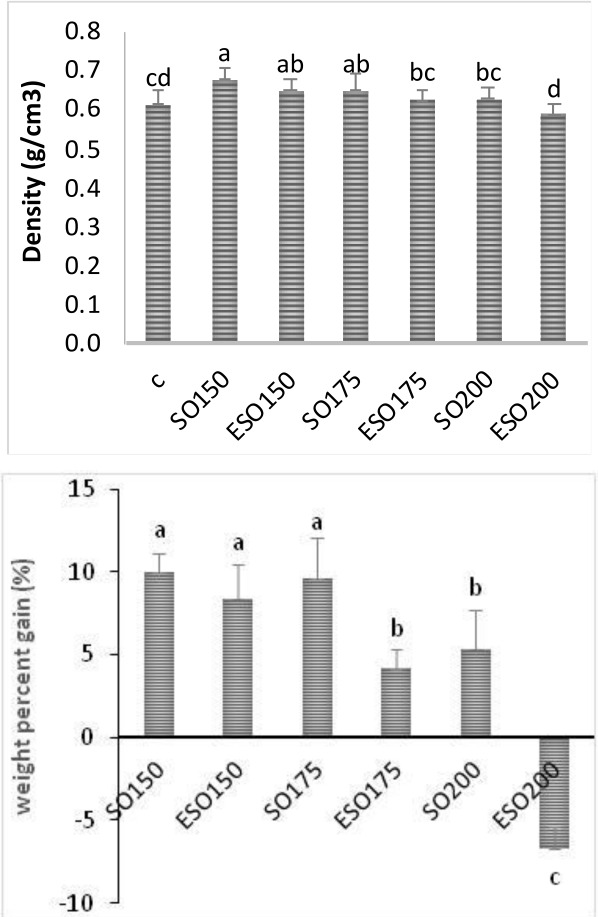


Fig. 1: Density (above) and Weight percent gain (WPG) (bottom) of control and modified samples

Temperature had significant effect on weight percent gain (WPG). WPG decreased with increasing temperature. Reduction of WPG was more sever in samples modified with epoxidized soybean oil, so that samples modified in epoxidized soybean oil showed mass loss which illustrated with negative WPG in Fig. 1b. Increase in weight caused by penetration of crude oil into the wood structure is more than that of epoxidized soybean oil. Probably, higher molecular weight of epoxidized oil prevented penetration of epoxy soybean oil into the wood structure which could compensate mass loss caused by the destruction of the wall. In 200 °C oil can not compensate mass loss occurred by destruction of wood component, especially in epoxy oil; because epoxy oil penetration is less than crude oil. Therefore, WPG increase in SO150, ESO150 and SO175, and decreased in ESO175, SO200 and became negative in ESO200.

*Mechanical properties of modified wood*

<u>Module of Elasticity (MOE) and Module of Rupture (MOR)</u>

The results showed that thermal modification in crude soybean oil at 150 °C did not cause significant change in modulus of rupture compared to the control sample. At this temperature, lignin condensation can prevent decrease of mechanical resistances, including bending and hardness strength (Abde et al. 2014).

Bending resistance decreased with the increase of heat treatment temperature. The lowest value of bending strength was reported at 200°C. However, with increase of temperature, the bending strength decreased significantly, which has been reported in other researches (Baar et al. 2020).

Comparison between two types of oil, at 150 °C, showed that the modulus of rupture of sample modified in epoxy soybean oil was significantly lower than the sample modified in crude oil. This decrease was also observed at higher temperatures, but the difference was not significant (Fig. 3). Modification with epoxy soybean oil due to the presence of epoxy functional groups that can penetrate the cell wall, reduced the bending resistance, probably due to creating gap between the cellulose microfibrils of the wall (Ghasemi et al. 2023).

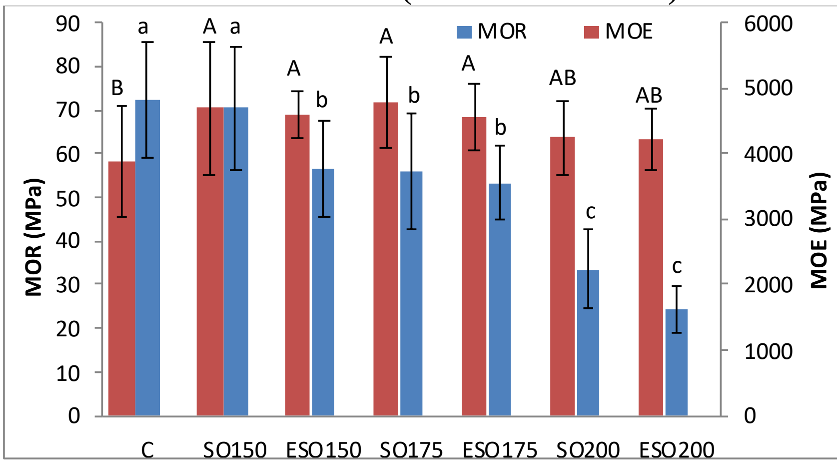

Fig. 3. MOE and MOR of control and modified Eucalyptus wood

Oil heat treatment increased MOE; however there was no significant difference among modified samples treated in different oils and temperatures. At higher temperature, degradation of cell wall polymers and shortening of cellulose chain length are the reasons for MOR and MOE reduction (Abde et al. 2014). Slight increase in MOE under milder treatment temperature explained by degradation of amorphous cellulose content and increase in the relative crystallinity (Kocaefe et al. 2008, Lee et al. 2018). Transformation of the wood amorphous polymeric materials from glassy state to plastic state at the glass-transition temperature and the hydraulic effects of oil present in the cavities also reported to justify increment in flexural modulus (Megnis et al. 2002, Lee et al. 2018).

Effect of Modification on hardness

Fig. 4 illustrates effect of oil heat treatment on hardness. Hardness increased in samples modified at 150 °C in both types of oil. However it decreased with increasing temperature to 175 and 200 °C. Comparison between two types of oil illustrates that sample modified with epoxy soybean oil had a higher decrease in hardness, which difference was statistically significant in ESO200.

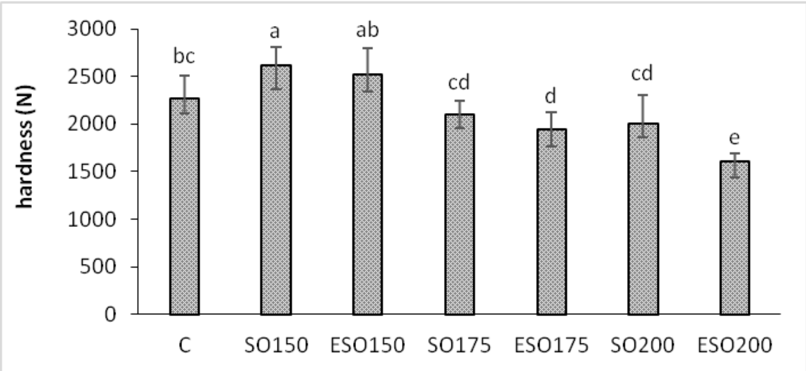

Fig 4. Hardness of control and oil heat treated samples

Oil heat treatment at 150 °C led to an increase in hardness in both types of oils. But increasing the temperature caused a decrease in hardness. The difference of hardness was not statistically significant between samples modified in two different oils. The increase in surface hardness in heat treatment at lower temperature (around 150 °C), can occur as a result of lignin condensation and creation of new chemical bonds (Juizo et al. 2020). However, increasing the heat treatment temperature caused a decrease in hardness due to the destruction of the components of the cell wall (Ghasemi et al. 2023, Fang et al. 2012).

Effect of modification on impact bending

The results showed that thermal modification caused a significant and severe reduction in impact bending resistance (Fig. 5). The untreated control sample had the highest impact resistance. The impact bending resistance decreased as the temperature increased. Modified samples in epoxy soybean oil at 150 and 175 °C had more impact resistance. This increase was significant in ESO150. There was no significant difference between the impact resistances of modified wood in two types of oil at a temperature of 200 °C.

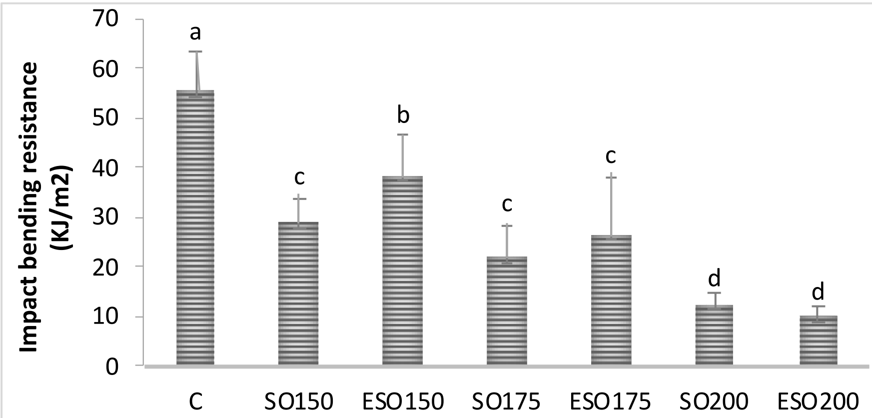


Fig. 6. Impact bending resistance of control and modified samples

Destroying the components of the cell wall during heat treatment led to brittleness of wood. High treatment temperature increases the intensity of the wall destruction led to decrease of impact bending resistance (Yang and Jin, 2021). In comparison between the two types of oil, samples modified in epoxy soybean oil with temperatures of 150 and 175 °C had higher impact resistance than the samples modified with crude oil. Ghasemi et al. (2023) and Terziev and Panov (2010) also reported an increase in the impact resistance of wood saturated with epoxy oil compared to crude oil. Impregnation of wood with epoxy oil due to the ability of oil to penetrate the cell wall and the placement of long chains of oil between cellulose microfibrils caused the weakening of the bond between the components of the cell wall and increased flexibility and as a result increased impact resistance (Ghasemi et al. 2023). However, increasing the modification temperature to 200°C increased the rigidity of the cell wall and as a result reduced flexibility and subsequently reduced impact resistance due to the formation of cross linkage.

## Conclusion

In general there were not significant differences between bending resistance and hardness of samples modified in two kinds of oils. Except for sample modified in epoxy oil at 150°C, which showed significant reduction in bending resistance compare to SO150. Oil heat treatment decreased bending resistance. However hardness increased at 150°C and then decreased with increasing temperature. Oil heat treatment caused a sharp reduction in impact bending resistance. The impact resistance of the samples modified in epoxy oil at 150°C was higher than the samples modified in the crude oil.

## References

Fang CH, Cloutier A, Blanchet P, Koubae A (2012) Densification of wood veneers combined with oil-heat treatment Part 2: Hygroscopicity and mechanical properties, Bioresources, 6(1): 925-935.

Ghasemi M, Dastoorian F, Abedini R, Amininasab M (2023) Effect of Combined Heat Treatment/Densification on Mechanical Properties of Poplar Wood Impregnated with epoxidized soybean oil, Journal of wood and forest science and technology 30(2):137-125 (in Persian).

Juizo CGF, Pereira da Rocha M, Nogueira Xavier C, Moreira Moraes A, Bezerra de Oliveira M, Moreira da Silva JR, (2020) Thermal Modification Of Eucalyptus Wood And Use For Floors Of Low Traffic Environment. FLORESTA, Curitiba, 51(2):457-465.

Kocaef D, Poncsak S, Boluk Y, (2008) Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen, BioResources, 3: 517–537.

Lee SH, Ashaari Z, Lum WCH, Halip JA, Ang AF, Tan LP, Chin KL, Tahir PM, Thermal treatment of wood using vegetable oils: A review, 2018. Construction and Building Materials, 181: 408–419.

Megnis M, Olsson T, Varna J, Lindberg H, (2002) Mechanical performance of linseed oil impregnated pine as correlated to the take-up level, Wood Science Technology, 36: 1–18.

Nejad M, Dadbin M, Cooper, P, (2019) Coating performance on exterior oil-heat treated wood. Coatings, 9(4): 225.

Sandberg D, Kutnar A, Mantanis G, (2017) Wood modification technologies - a review, iForest biogeosciences and Forestry, 10: 895-908.

Terziev N, Panov D (2010) Plant Oils As “Green” substances for wood protection. In: 4th international conference on environmentallycompatible forest products, At Porto, Portugal, p. 143–149.

Tjeerdsma BF, Swager P, Horstman B, Holleboom W, Homan J (2005) Process development of treatment of wood with modified hot oil, European Conference on Wood Modification, Göttingen, Germany, p. 1-10.

Yang L, Jin H, (2021) Effect of Heat Treatment on the Physic-Mechanical Characteristics of Eucalyptusurophylla S.T. Blake, Materials, 14(21):6643.