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# Some mechanical properties of plywood produced using with polyethylene as adhesive from different wood species

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**Abstract**

*Aim of study:* Investigation of some mechanical properties of panels produced using polyethylene waste as adhesive instead of formaldehyde-based resins used in plywood was aimed and polyethylene amount was tried to determine for plywood produced from different wood species.

*Area of study:* This study was conducted at the Pilot Facility of Department of Forest Industry Engineering, Karadeniz Technical University in Trabzon, Turkey.

*Material and Methods:* Beech (*Fagus Orientalis Lipsky*), alder (*Alnus glutinosa* subsp. *barbata*) and Scots pine (*Pinus sylvestris* L.) veneers were used to produce polyethylene plywood. Three different polyethylene amounts was used (160, 200 and 240 gr/m$^2$). Density, shear strength, bending strength and modulus of elasticity of plywood panels were determined according to TS EN 323-1, TS EN 314-1 and TS EN 310, respectively.

*Main results:* The best mechanical strength values for beech and alder were obtained from panels produced using 200 gr/m$^2$ polyethylene amounts. Moreover, these values for Scots pine were found in panels produced using 160 gr/m$^2$ polyethylene amounts.

*Research highlights:* When this study applies in the plywood industry, can provide to both recycle polyethylene waste and prevent formaldehyde release. Polyethylene plywood waste can be used production of wood plastic composite panels.

**Keywords:** Polyethylene waste, Composite, Plywood, Mechanical properties, Wood species.

# Farklı ağaç türlerinden bağlayıcı olarak polietilen kullanılarak üretilen kontrplakların bazı mekanik özellikleri

**Özet**

*Çalışmanın amacı:* Kontrplak sektöründe kullanılan formaldehit esaslı reçineler yerine bağlayıcı olarak atık polietilen kullanılmasıyla üretilmiş levhaların bazı mekanik özelliklerinin araştırılması amaçlanmış ve farklı ağaç türlerinden üretilmiş levhalar için optimum polietilen miktarları belirlenmeye çalışılmıştır.

*Çalışma alanı:* Bu çalışma, Trabzon'daki Karadeniz Teknik Üniversitesi Orman Endüstri Mühendisliği Bölümü Pilot tesisinde yapılmıştır.

*Materyal ve Yöntem:* Kayın (*Fagus Orientalis Lipsky*), kızılağaç (*Alnus glutinosa* subsp. *barbata*) ve sarıçam (*Pinus sylvestris* L.) kaplamalar, polietilen kontrplakların üretiminde kullanılmıştır. Üç farklı polietilen miktarı seçilmiştir (160, 200 ve 240 gr/m$^2$). Üretilen levhaların y TS EN 323-1, çekme makaslama direnci TS EN 314-1, eğilme direnci ve elastikiyet modülü ise TS EN 310 standartlarına göre belirlenmiştir.

*Sonuçlar:* En iyi mekanik direnç değerleri, kayın ve kızılağaç için 200 gr/m$^2$ polietilen miktarı kullanılarak üretilen levhalardan elde edilmiştir. Ayrıca, sarıçam için en iyi değerler ise, 160 gr/m$^2$ polietilen miktarı kullanılarak üretilen levhalarda bulunmuştur.

*Araştırma vurguları:* Bu çalışma, kontrplak endüstrisinde uygulanmasıyla birlikte hem polietilen atıkların geri dönüşümü sağlanabilir, hem de levhalardaki formaldehit salınımı önlenebilir. Polietilen ile üretilen kontrplakların atıkları, ahşap plastik kompozit panellerin üretiminde de kullanılabilir.

**Anahtar Kelimeler:** Atık polietilen, Kompozit, Kontrplak, Mekanik özellikler, Ağaç türü.

## Introduction

Due to the increasing demand for wood products and the decreasing in the quality and presence of wood raw materials, the importance of composite wood products has increased steadily. This has led to an enormous increase in the use of adhesives in the forest products industry and has improved the use of wood raw materials resources. It is stated that adhesives used in about 70% of application in forest product industry (Aydin, Demirkir, Colak & Colakoglu, 2010, p. 1826). At present, urea formaldehyde and phenolic resins are the adhesives used mainly in plywood production and account for 87.1% and 9.6% of all adhesives used in plywood manufacture, respectively, in 2004 (Qian, 2006, p. 12). Urea formaldehyde resin is non-flammable, has good adhesive strength, is resistant to changes in high temperature, light and corrosion, and has a short curing time, simple production technology and low production costs. But it also has a number of disadvantages, such as a high curing shrinkage ratio, a brittle colloidal property, weak water resistance and formaldehyde emission. Phenolic resins are able to enhance bonding strength and water resistance, but they require a long curing time, high curing temperatures, and have high production costs and emit formaldehyde and phenol (Cui, Song & Zhang, 2010, p. 218). Formaldehyde release depend on content of release cause adverse health effects such as eye and respiratory irritation, irritability, inability to concentrate and sleepiness (Colak & Colakoglu, 2004, p. 533). Also, The International Agency for Research on Cancer (IARC) in 1995 attached to formaldehyde in terms of human health "Possible Carcinogenic Substances" class and the ratio of formaldehyde can release from wood based materials was limited in most of country (IARC, 2004; Colakoglu, 1993, p. 21). After this area investigated comprehensively, IARC in June 2004 removed formaldehyde from "Possible Carcinogenic Substances" class and identified as an agent caused directly carcinogen for human (Jianying, Tao, Yingyan, Min & Xia, 2010, p. 1). It is started to prefer alternative adhesives or using formaldehyde scavenger prevented formaldehyde release in industry due to this disadvantage of formaldehyde based resins. Although some of these new adhesives have already been used in industrial applications, their supply is limited which may be due to the high modification costs or some their poor properties, for example, low wood resistance (Fang, Chang, Guo, Ren & Wang 2013, p. 740). Therefore, the chemicals or adhesives to be used must be both cheap and easily accessible, and the wood-based panels should also meet the technological properties that they should possess (Colak, Ozturk & Demir, 2016, p. 22).

In Turkey, the composition of solid waste changes with the changing consumption habits, population growth, rising standard of living, increased sales of packaged products. Generally, 20% by weight and 50% by volume of the formed wastes constitute packaging wastes (Official Gazette, 2014). The recycling of polyethylene, which form a significant part of packaging waste, due to not dissolving in the nature for a long time as well as the harmful gases given to the atmosphere by burning are very important. (Colak et al., 2016, p. 22). In literature, it was shown that the wood based panels obtain from using plastic and textile fibers waste are petrochemical materials as an adhesive gave successful results (Cui et al., 2010, p. 218; Kajaks, Reihmane, Grinbergs & Kalnins, 2012, p. 207; Kofi, 2014, p. 1). From this, it is thought that polyethylene, which is a petrochemical and constitutes a serious waste potential for our country, can also be evaluated in the plywood industry.

In this study, some mechanical properties of panels were produced using polyethylene waste as adhesive instead of formaldehyde-based resins was aimed to investigate and amount of polyethylene was tried to determine for wood species on plywood production.

## Material and Methods

In this experimental study, 2 mm-thick rotary cut veneers with the dimensions of 500 mm by 500 mm were obtained from beech (*Fagus orientalis Lipsky*), alder (*Alnus glutinosa* subsp. *barbata*) and Scots pine (*Pinus sylvestris* L.) logs. While the alder veneers were manufactured from freshly cut logs, beech and Scots pine logs were steamed for 12 h before veneer production. The horizontal opening between knife and nosebar was 85% of the veneer thickness, and the vertical opening was 0.5 mm in rotary cutting process. The veneers were then dried to 6–8% moisture content with a veneer dryer. After drying, it was formed plywood panel drafts. The draft of polyethylene plywood is shown in Figure 1.

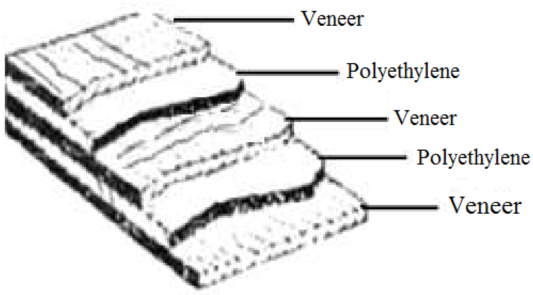


Figure 1. Draft of polyethylene plywood

Three-ply-plywood panels with 6 mm thick were manufactured by polyethylene wastes. The polyethylene wastes were lay outed at rates of 160, 200 and 240 g/m$^2$ to the single surface of veneer. Hot press pressure was 12 kg/cm$^2$ for beech and alder and 8 kg/cm$^2$ for scots pine panels while hot pressing time and temperature were 15 min and 150ºC, respectively. Two replicate panels were manufactured for each test groups.

The density, shear strength, bending strength and modulus of elasticity of polyethylene plywood panels were determined according to TS EN 323-1 (1999), TS EN 314-1 (1998), and TS EN 310 (1999) standards, respectively.

## Results and Discussion

Duncan's test results of polyethylene plywood panels according to wood species and polyethylene amounts were presented in Table 1. Moreover, graphs of each measured technological properties were given Figure 2.

Table 1. Duncan's test results of polyethylene plywood panels ($P < 0.05$)*.

| Wood Species | Nylon Amounts (gr/m$^2$) | Specific Gravity (g/cm$^3$) | | Shear Strength (N/mm$^2$) | | Bending Strength (N/mm$^2$) | | Modulus of Elasticity (N/mm$^2$) | |
|---|---|---|---|---|---|---|---|---|---|
| | | n | X | n | X | n | X | n | X |
| Beech | 160 | 15 | 0.729 c | 20 | 1.52 b | 8 | 76.31 a | 8 | 6459 a |
| | 200 | 15 | 0.697 b | 20 | 1.57 b | 8 | 118.8 b | 8 | 8340 c |
| | 240 | 15 | 0.633 a | 20 | 1.45 a | 8 | 113.3 b | 8 | 7108 b |
| Alder | 160 | 15 | 0.637 c | 20 | 1.47 b | 8 | 62.37 a | 8 | 5129 a |
| | 200 | 15 | 0.610 b | 20 | 1.52 b | 8 | 64.44 b | 8 | 6036 b |
| | 240 | 15 | 0.561 a | 20 | 1.10 a | 8 | 59.77a | 8 | 5249 a |
| Scots pine | 160 | 15 | 0.530 b | 20 | 1.36 c | 8 | 56.13 b | 8 | 5218 b |
| | 200 | 15 | 0.490 a | 20 | 1.23 b | 8 | 52.72 b | 8 | 4117 a |
| | 240 | 15 | 0.528 b | 20 | 1.06 a | 8 | 37.12 a | 8 | 3647 a |

n: Specimen numbers X: Arithmetic mean
* The mean values marked with the same symbol are statistically identical.

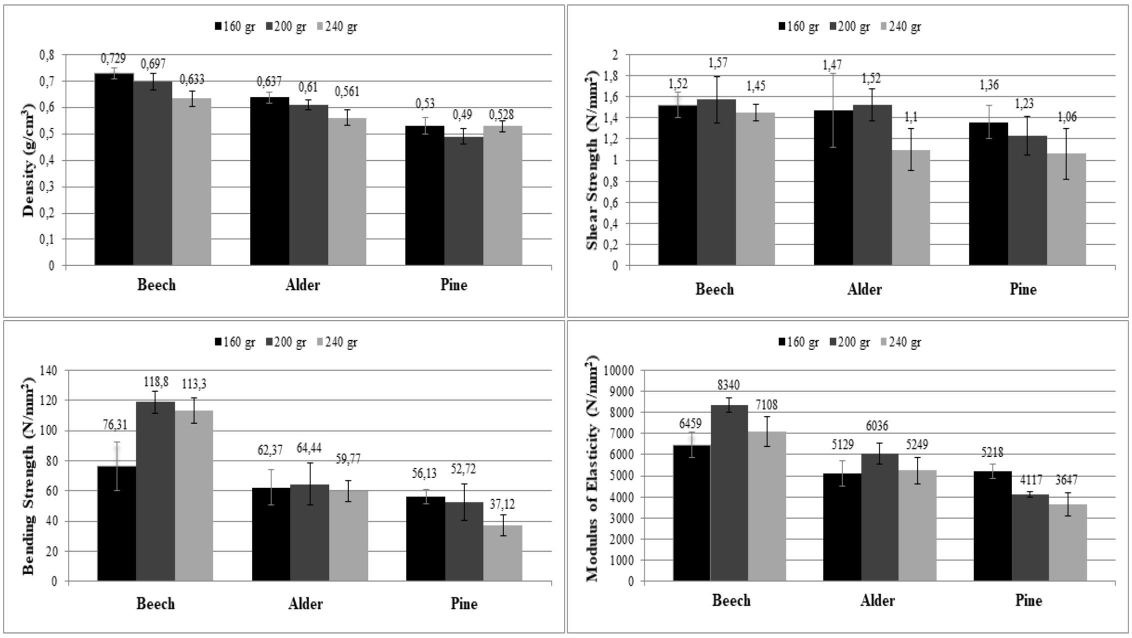


Figure 2. Technological properties of polyethylene plywood panels

As can be seen from Table 1 and Figure 2, the best mechanical strength values for beech and alder were obtained from panels produced using 200 gr/m$^2$ polyethylene amounts. Moreover, these values for Scots pine were found in panels produced using 160 gr/m$^2$ polyethylene amounts and decreased with increasing polyethylene amount. In the previous study, it was to investigate of the some technological properties of plywood panels manufactured with polyethylene waste and Scots pine veneers and optimal press conditions and polyethylene amount (140, 160 and 180 g/m$^2$) were determined for the panels. As a result of the study, the best mechanical strength values of polyethylene plywood panels were obtained from 160 g/m$^2$ polyethylene amount (Colak et al., 2016, p. 25). Fang et al. (2013) produced wood-plastic plywood bonded with high density polyethylene film. They found that polyethylene dosage positively affects the properties when ranging from 61.6 to 246 g/m$^2$ and when the dosage increased from 61.6 to 246 g/m$^2$, dry and wet strength of the plywood increased as much as 46.8 and 100 %, respectively. Polyethylene film was able to penetrate into the vessels of the wood substrate to form bonded joints when the pressing temperature was higher than the melting point. These bonded joints made the mechanical interlock work and gave strength to the plywood.

As the amount of polyethylene used decreases, the density values of the produced plywood sheets increase (Figure 2). It is thought that the low weight polyethylene plywood produced higher density values due to a thinner adhesion layer and a tighter mechanical bond in the bond line.

The all of shear strength values of polyethylene plywood panels were higher than 1 N/mm$^2$ determined according to DIN 68705-3 (2003). The bending strength and modulus of elasticity values of polyethylene plywood panels were higher than 40 and 4000 N/mm$^2$ determined according to DIN 68705-3 (2003), respectively. Scots pine panels produced using 240 gr/m$^2$ polyethylene amounts did not provide DIN 68705-3 (2003), but they exceeded 34.47 N/mm$^2$ determined according to the form was arranged by APA (2010) and showed the mechanical properties of structural plywood panels. Colak et al. (2016) stated that molten state polyethylene, depend on both wood processing and wood anatomical structure, penetrates into porous structure of wood and filled cracks and cavities on surfaces, and this helps to have smoother veneer surfaces. In literature, it was stated that smooth surface veneer bonded better than rough surface veneer and so it shows better performance on mechanical properties (Frihart, 2005, p. 225).

**Conclusion**

This study investigated that the some mechanical properties of panels were produced using polyethylene waste as adhesive instead of formaldehyde-based resins used in plywood and polyethylene amount was tried to determine for plywood produced from different wood species. As a result of this study; Formaldehyde-free polyethylene plywood has been successfully produced using polyethylene waste as wood adhesive. This novel plywood shows considerable mechanical properties. The panels produced using 200 g/m$^2$ polyethylene amounts gave the best mechanical strength values for beech and alder. Moreover, these values for Scots pine were achieved in panels produced using 160 g/m$^2$ polyethylene amounts and decreased with increasing polyethylene amount. When this study applies in the plywood industry, can provide to both recycle polyethylene waste and prevent formaldehyde release. Polyethylene plywood waste can be used production of wood plastic composite panels.

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