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Araştırma Makalesi Research Article

DESIGN AND PROPERTIES OF COMPOSITE SUSTAINABLE BUILDING MATERIAL BY USING WASTE HDPE

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Keywords
Sustainable Building Materials,
Waste HDPE,
Plywood,
Industrial Product Design,
Recycling,
Technological Properties.

Abstract
The aim of this study is to produce next generation of sustainable building materials by using wood veneers and waste plastics. In this study, plywood was produced using poplar (Populus Euphratica) veneer and waste high-density polyethylene (HDPE). Four different high-density polyethylene amounts were used (170 g/m², 200 g/m², 240 g/m² and 280 g/m²). Some technological properties such as density, modulus of elasticity (MOE), modulus of rupture (MOR), and impact bending (IB) were investigated according to Turkish standards TS EN 323, TS EN 310, TS EN 310 and TS 2477, respectively. According to obtained data, the density, MOR, MOE and IB values are increased by increasing the usage rate of HDPE in composite production.

ATIK HDPE KULLANILARAK SÜRDÜRÜLEBİLİR KOMPOZİT YAPI MALZEMESİ TASARIMI VE ÖZELLİKLERİ

Anahtar Kelimeler
Sürdürülebilir Yapı Malzemesi,
Atık HDPE,
Kontrplak,
Endüstriyel Ürün Tasarımı,
Geri Dönüşüm,
Teknolojik Özellikler.

Öz
Bu çalışmanın amacı, ahşap kaplama ve atık plastik kullanarak yeni nesil sürdürülebilir yapı malzemesi üretmektir. Bu araştırmada, kavak (Populus Euphratica) kaplama ve dört farklı yoğunluğa sahip (170 g/m², 200 g/m², 240 g/m² ve 280 g/m²) yüksek yoğunluklu polietilen (HDPE) kullanılarak kontrplak üretilmiştir. Üretilen kompozit malzemelerin hava kurusu yoğunluk (TS EN 323), eğilme direnci (TS EN 310), eğilmede elastikiyet modülü (TS EN 310) ve şok direnci (TS 2477) gibi teknolojik özellikleri araştırılmıştır. Elde edilen test sonuçlarına göre, kontrplak üretiminde kullanılan yüksek yoğunluklu polietilenin (HDPE) kompozit malzeme içerisindeki yoğunluğunun artmasına paralel bir şekilde teknolojik özelliklerde de artış kaydedildiği tespit edilmiştir.

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1. Introduction

Plastic waste can remain intact for centuries in nature. Nearly half of the produced plastics float on the surface of the oceans. While some of the materials made of plastic are produced to be used for a long time, most of them are designed and produced for short-term use. High- density polyethylene (HDPE) is widely used worldwide because HDPE has a wide variety of applications. Also, today there are plastic wastes around us and even in the most remote corners of the world. Environmental pollution caused by plastic causes thousands of animals to die every day and serious damage to the ecosystem. However, plastic is a recyclable material. The issue of recycling plastic waste and reducing plastic waste is very important for the future of the world.

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It is possible to recycle waste plastics by producing wood plastic composites. Wood plastic composite can be produced with wood lamination technique. Recently, when we examine the studies about wood-based building materials, it is seen that the use of some materials other than wood in lamination gives impressive results (Wangaard, 1964; Biblis, 1965; Rowlands et al., 1986; Pidaparti and Johnson, 1996; Hallstrom and Grenestedt, 1997; Fiorelli and Dias, 2006; Güler and Subaşı, 2011; Basterra et al., 2012; Bal and Özyurt, 2015; Taheri et al., 2009; Özyurt and Ayrılmış, 2018; Luggin and Beıgmeister, 1998).

Wood and wood-based materials are preferred as sustainable building materials. Plywood can be defined as structural composite timber. Plywood is widely used as building material. It is produced by pressing the fiber directions perpendicular to each other with the help of suitable glue by using thin wood veneer (See figure 1). It is a natural and recyclable material because it is produced from wood.

However, the use of glue increases the cost of the composite material and causes the release of harmful gases. In this research, waste plastic was used instead of glue in lamination. Thus, the production cost of plywood used as construction material has been reduced. In addition, it is aimed to improve the technological properties of wood material by using waste plastic (HDPE).

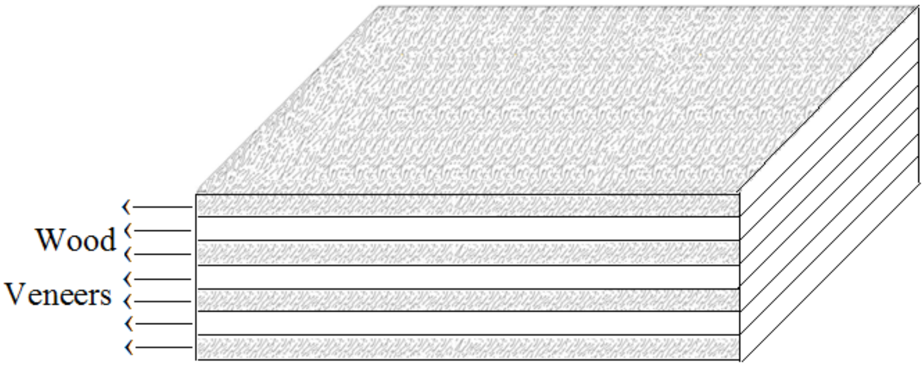

Figure 1. Schematic image of the plywood

2. Materials and Methods

2.1. Materials

In this research, with a thickness of 2.8 millimeters peeling veneers obtained from poplar (Populus Euphratica) were used. The poplar veneers were purchased from a special manufacturer. Four different waste high-density polyethylene (HDPE) amounts were used (170 g/m^2, 200 g/m^2, 240 g/m^2 and 280 g/m^2).

2.2. Methods

Plywood-HDPE composite boards were produced as seven layers (fiber directions perpendicular to each other). Adhesive was not used in plywood production. Waste high-density polyethylene sheets (HDPE) were used instead of glue in plywood production.

Seven wood veneer sheets and waste HDPE sheets pressed (See Figure 2) in hot press (140°C temperature, 7 kg/cm^2 press pressure). Four experimental groups were created. These are group A (waste HDPE amount is 170 g/m^2), group B (waste HDPE amount is 200 g/m^2), group C (waste HDPE amount is 240 g/m^2) and group D (waste HDPE amount is 280 g/m^2). Fifteen boards were manufactured for each group (The plywood-HDPE composite boards measuring 60 cm width, 60 cm length, 2 cm thickness), totaling 60 Plywood-HDPE composite boards. The test samples were conditioned at 20±3 °C and 65±5% relative humidity until stable weight (almost 25 days).Some technological properties such as density, modulus of elasticity (MOE), modulus of rupture (MOR), and impact bending (IB) were investigated according to Turkish standards TS EN 323 (1999), TS EN 310 (1999), TS EN 310 (1999) and TS 2477 (1976), respectively. The MOE, MOR and IB tests of Plywood-HDPE composite were performed in edgewise and flatwise direction (See Figure 3).

The technological properties of Plywood-HDPE were also determined according to equations given in below;

$D_{12} = W_{12}/V_{12}$ where; D_{12} is Air dry density (gr/cm^3), W_{12} is air dry weight of test samples (gr), V_{12} is air dry volume (cm^3) of test samples (TS EN 323, 1999). Also,

$\sigma_{MOR} = 3.P_{max}.L/2.b.h^2$ where; σ_{MOR} is modulus of rupture (MPa), P_{max} is maximum force at the time of rupture (N), L is the span between supports (mm), b is the width of the specimens (mm), h is the height (mm) of the specimens (TS EN 310, 1999). Also,

$\sigma_{MOE} = \Delta F.L^3/\Delta f.4.b.h^3$ where; σ_{MOE} is modulus of elasticity (MPa), ΔF is the force difference applied in the elastic deformation zone, Δf is bending amount difference of the test specimen, L is the span between supports (mm), b is the width of the specimens (mm), h is the height (mm) of the specimens (TS EN 310, 1999). Finally,

$\sigma_{IB} = Q/bxh$ where; σ_{IB} is impact bending (kgm/cm^2), Q is absorbing energy (kgm), b is the width of specimen (cm), and h (cm) is the thickness (TS 2477, 1976).

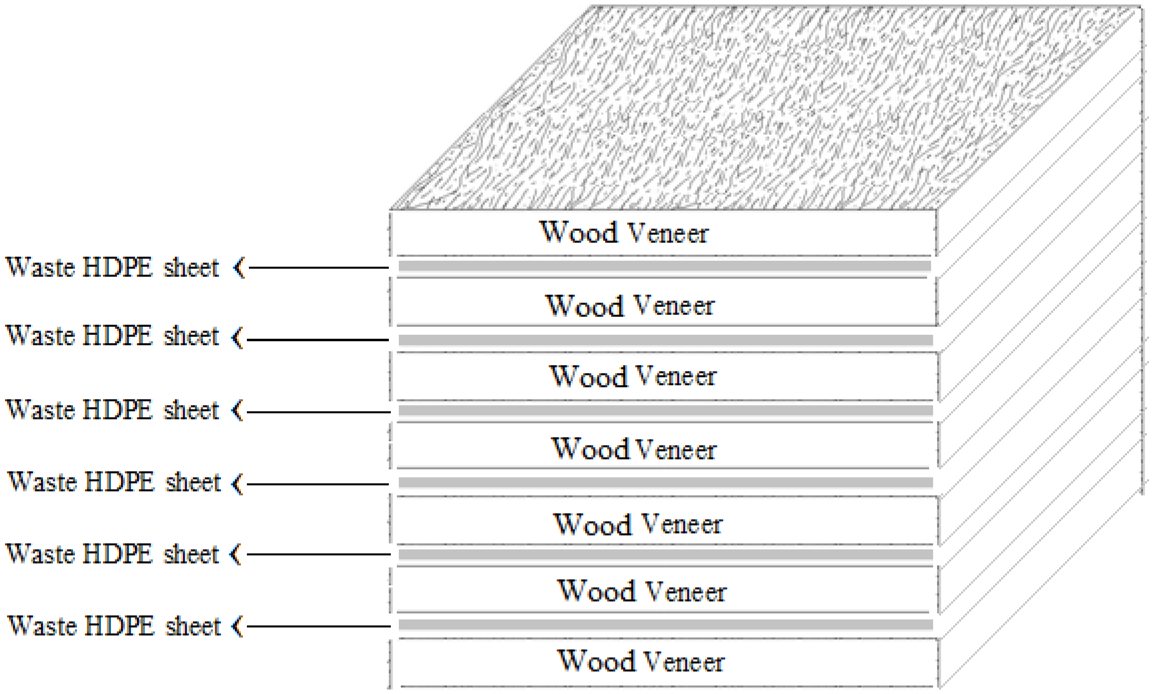

Figure 2. Schematic representation of the experimental groups (A,B,C and D)

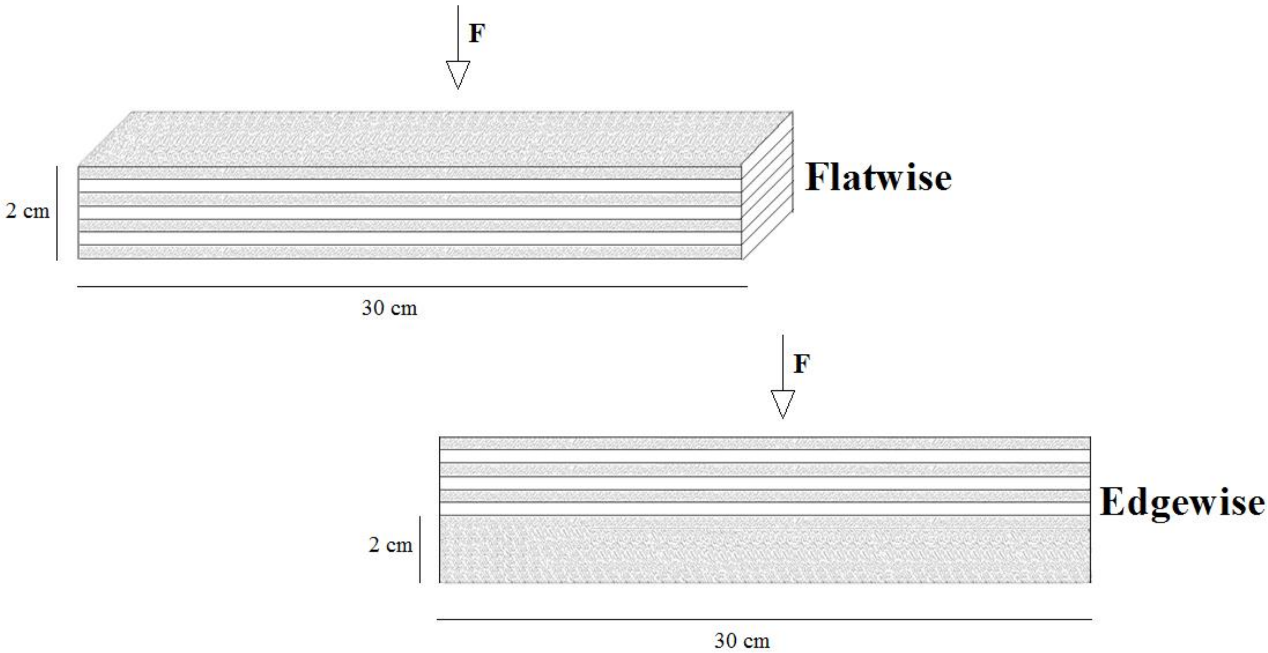

Figure 3. Positions Flatwise and Edgewise of the test specimens in the MOR, MOE and IB tests

3. Results and Discussion

When table 1 and table 2 are examined in detail, modulus of rupture (MOR), modulus of elasticity (MOE), impact bending (IB) and air dry density values of the experimental groups range from 65.09 MPa to 79.24 MPa , 5671 MPa to 7447 MPa, 0.41 kgm/cm^2 to 0.81 kgm/cm^2 , 0.44 gr/$\mathbf{cm^3}$ to 0.55 gr/$\mathbf{cm^3}$,respectively. The modulus of rupture, modulus of elasticity and impact bending of flatwise direction were found to be better than edgewise direction. Technological properties (Air dry density, MOR, MOE and IB) of D group were determined higher than other groups. Air dry density value was found as 0.44 gr/$\mathbf{cm^3}$, 0.47 gr/$\mathbf{cm^3}$, 0.52 gr/$\mathbf{cm^3}$ **and** 0.55 gr/$\mathbf{cm^3}$ for A group, B group, C group and D group, respectively. Use of waste high-density polyethylene (HDPE) in the production of plywood increased density of the composite material. Similar results have been reported by Bal and Özyurt (2015). The modulus of rupture, modulus of elasticity and impact bending and air dry density values are increased by increasing the usage rate of waste high density polyethylene (HDPE) in composite production.

Table 1. The MOR, MOE and IB values of plywood-HDPE

N:100		Flatwise Direction			Edgewise Direction		
		MOR (MPa)	MOE (MPa)	IB (kgm/cm^2)	MOR (MPa)	MOE (MPa)	IB (kgm/cm^2)
Group A	x	66.15	5750	0.42	65.09	5671	0.41
	s	2.14	339	0.04	3.35	407	0.04
Group B	x	69.54	6112	0.55	68.69	6003	0.49
	s	3.07	235	0.06	2.60	496	0.07
Group C	x	74.96	6846	0.72	72.24	6709	0.64
	s	2.51	197	0.07	2.72	501	0.06
Group D	x	79.24	7447	0.81	77.99	7313	0.78
	s	3.10	381	0.05	2.89	413	0.07
x: mean value, s: standard error, N: the number of samples in each group							

Table 2. Air dry density values of plywood-HDPE

N:100		Group A	Group B	Group C	Group D
Density (gr/cm^3)	x	0.44	0.47	0.52	0.55
	s	0.02	0.04	0.05	0.04
X: mean value, s: standard error, N: the number of samples in each group					

According to MOR test results, the highest value was measured in group D as 79.24 MPa and the lowest value in A group as 65.09 MPa. Modulus of rupture values of A (flatwise- edgewise), B (flatwise- edgewise), C (flatwise- edgewise) and D (flatwise- edgewise) groups were determined as 66.15 MPa - 65.09 MPa , 69.54 MPa – 68.69 MPa , 74.96 MPa – 72.24 MPa , 79.24 MPa – 77.99 MPa, respectively. The modulus of rupture (MOR) values are increased by increasing the usage rate of waste high-density polyethylene (HDPE) in plywood production (See Figure 4). Similar results about MOR have been reported by Güler and Subaşı (2011).

When modulus of elasticity (MOE) test results are examined, MOE values of A (flatwise- edgewise), B (flatwise- edgewise), C (flatwise- edgewise) and D (flatwise- edgewise) groups were determined as 5750 MPa – 5671 MPa, 6112 MPa – 6003 MPa, 6846 MPa – 6709 MPa , 7447 MPa – 7313 MPa, respectively. The D group showed higher mean value of MOE, while the A group had the lowest mean value of MOE (See Figure 5). It is believed that under static loading modulus of elasticity (MOE) values of the experimental groups (A, B, C and D) have increased because of waste high-density polyethylene (HDPE) and wood veneer were modified. Similar results about MOE have been noted by other researchers (Fiorelli and Dias, 2006; Hallstrom and Grenestedt., 1997).

According to impact bending (IB) test results, IB values of the experimental groups have increased significantly. The IB values of A (flatwise- edgewise), B (flatwise- edgewise), C (flatwise- edgewise) and D (flatwise- edgewise) groups were determined as 0.42 kgm/cm^2- 0.41 kgm/cm^2 , 0.55 kgm/cm^2 – 0.49 kgm/cm^2 , 0.72 kgm/cm^2 – 0.64 kgm/cm^2 , 0.81 kgm/cm^2 – 0.78 kgm/cm^2 , respectively. When the results are examined in detail, compared to group A, percentage increase IB of B (flatwise- edgewise), C (flatwise- edgewise) and D (flatwise- edgewise) groups were determined as % 31 - % 19, % 71 - % 56, % 92 - % 90, respectively (See Figure 6). It is thought that under dynamic loading impact bending (IB) resistance of the experimental groups (A, B, C and D) have increased owing to waste high-density polyethylene (HDPE) with composite material were integrated. Similar results about IB have been reported by Özyurt and Ayrılmış (2018).

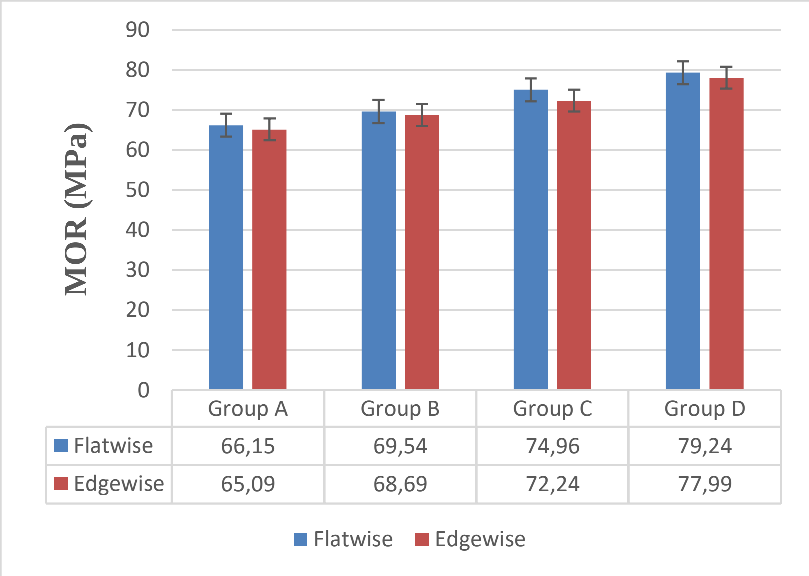

Figure 4. Comparison of the MOR values of experimental groups

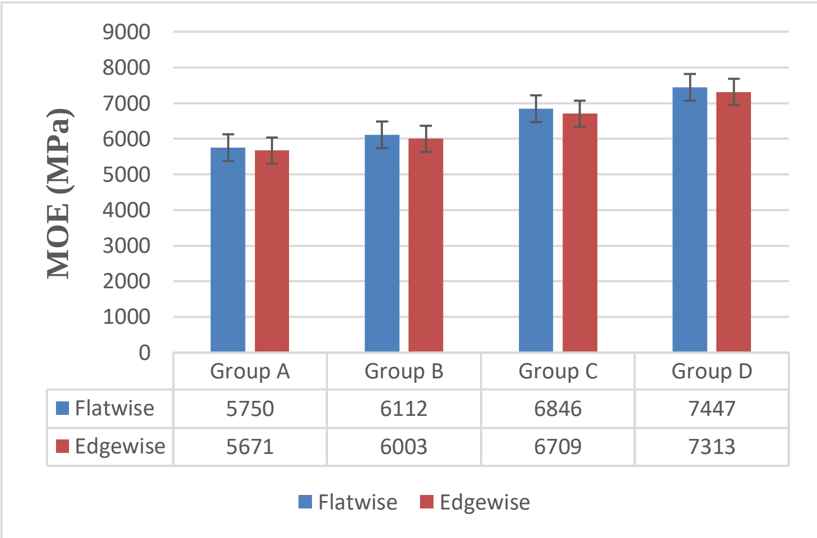

Figure 5. Comparison of the MOE values of experimental groups

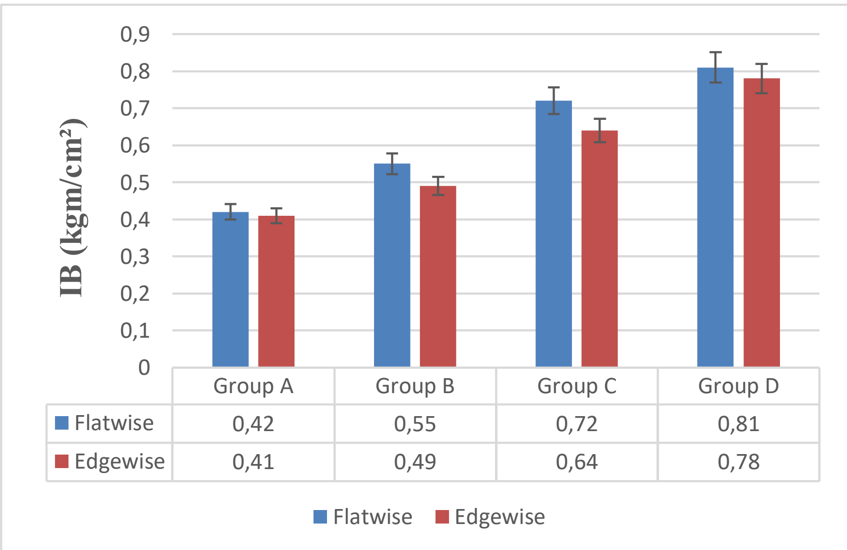

Figure 6. Comparison of the IB values of experimental groups

4. Conclusion and Suggestions

In this study, sustainable building materials (plywood-HDPE composite) was produced by using waste high-density polyethylene (HDPE) and some technological properties were investigated. The test results showed that:

1. It is possible to recycle the waste high-density polyethylene (HDPE) using plywood production.
2. The production cost of composite material was reduced by using waste HDPE instead of glue in plywood production.
3. It is technically possible to use waste HDPE in the design and production of sustainable building materials.
4. The modulus of rupture (MOR), modulus of elasticity (MOE) and impact bending (IB) values of flatwise direction were determined to be higher than edgewise direction.
5. Use of high-density polyethylene in the production of plywood increased density of the composite material, which led to the development of technological properties.
6. Compared other experimental groups (A, B and C), it has been determined that group D has the highest technological properties.
7. Wood and wood-based composites are natural materials because they are made from trees. Wood plastic composites (WPC) have very important properties such as low cost, wastes recyclability, eco-friendly and low carbon footprint. Also, they have high technological properties. It is thought that the rate of use of wood plastic composites in the construction sector, interior and exterior architecture, and furniture production should be increased.

Conflict of Interest

No conflict of interest was declared by the author.

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