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Investigating the usability of terrestrial animal and fish bones in the production of polymer composites

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Abstract

Increasing raw material requirements with developing technologies leads to the search for new materials. This study investigated the usability of terrestrial animal and fish bones, which are considered waste, in producing polymer composites. In this context, composite panels were produced by mixing the materials as chip form into high-density polyethylene (HDPE) polymer homogeneously at the rate of 10–30–50% by weight. Some of the physical and mechanical properties of produced panels were investigated and compared with the results of some referenced research that studied wood-plastic composites (WPC). The results of the study provided important insight into the usability of terrestrial animal and fish bones in polymer composite production. As a result, it can be concluded that the panel produced with terrestrial animal and fish bone may be suitable to use in case of water resistance required but in non-load bearing conditions.

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Introduction

Due to increasing environmental concerns, composite materials have attracted great attention in recent years. In addition to offering superior properties compared to its own components, it enables more efficient use of potential raw materials. Wood-plastic composite (WPC) is one of the well-known examples of them. WPC has continued to develop over the last 50 years and the application areas of WPC are constantly expanding for both structural and non-structural applications such as decking materials, fences, window and door frames, furniture, siding, timber, playground equipment, docks, bridges, and traverses (Smith and Wolcott, 2006; Schwarzkopf and Burnard, 2016). WPC has mainly produced by the thermoplastic polymers (polyethylene (PE)), polypropylene (PP), polyvinyl chloride (PVC) and polystyrene (PS) and the biomass particles and fibers from forestry and agricultural wastes (wood, bamboo, straw, stalk, husk and bast) (Deka and Maji, 2011; Adhikary et al., 2011).

Like forestry and agricultural wastes, a considerable amount of terrestrial animal and fish residue is produced in the world every year. Seafood production has increased every year and reached 177 million 834 thousand tons in 2019 in the world (FAO, 2021). An increase in daily seafood production causes many processing residues that must be disposed of. Evaluation of fish waste is a subject on which researches are concentrated. In order to evaluate these residues, many different methods are tried together with technological development. The residues are used in pharmaceuticals, cosmetics, feed and many other industrial areas by undergoing various processes. Globally, 60% of the fish caught is processed. This causes around 27.85 million tons of residues (Thirukumaran et al., 2022). Approximately 10–15% of the total mass of fish is bone (Toppe et al., 2006) and 15.3% ±4.6% of this bone is in the backbone and 21.5% ±4.3% is in the head. Fish bone constitutes the most important part of seafood residues (Thirukumaran et al., 2022; Toppe et al., 2006). Although fish bones are used in gelatin production, medical and dental fields or as fish meal and biofertilizer (Thirukumaran et al., 2022; Geahchan et al., 2022; Mutalipassi et al., 2021; Phadke et al., 2021; Ucak et al., 2021; V´azquez et al., 2021), these are applications that require extensive and expensive processes and cannot be met by every enterprise. Therefore, more research should be done on the methods of easy evaluation of fish bones in different areas.

To meet the meat consumption in the world, the amount of terrestrial animal production is increasing every year. Approximately 337.2 million tons of meat were produced globally in 2020 (Destatis, 2022). The most common solid waste of slaughterhouse is bone (Mengistu and Reshad, 2022). 30.4% of the residues from a cattle are bone. In worldwide meat production, approximately 0.13 billion tons of bone is produced as waste, annually (Mengistu and Reshad, 2022). Structure of bovine bones are same as fish bone. Animal bone consists of hydroxyapatite, has good thermal stability, beside filled with inorganic minerals such calcium and phosphorus, and has a porous crystal structure (Mengistu and Reshad, 2022). Beef bones can be evaluated as bone meal and bone oil moreover, glue and gelatin are obtained from them. Obadiah et al. (2012), used bones as a source of heterogeneous catalysts by carbonizing them. In addition, filters, light-sensitive photographs and x-ray films are produced from bones with undergoing different processes.

In this study, it is aimed to investigate the possibility of using fish and terrestrial animal bones as a filling material in plastic composites which is in a very different field than food, agriculture and medicine.

Methods and materials

Materials

Terrestrial animal and fish bone flour with a particle size of 20 to 40 mesh was used as a filling material and the powder form of high-density polyethylene (HDPE) (Ucar Plastic, Izmir, Türkiye) was used as polymer material, which were provided by commercial suppliers. The polymer's density and melt flow index (MFI) were 0.965 g.cm^3 and 5.5 g/10 min (190°C/2.16 kg), respectively. The experimental design that consist of mixing ratios of terrestrial animal and fish bone content and HDPE is given in Table 1.

Table 1. The content of filling flour and HDPE in the mixture

Terrastial animal bone flour		
Groups	Filling flour (%)	HDPE (%)
TABPC0	0	100
TABPC1	10	90
TABPC2	30	70
TABPC3	50	50
Fish bone flour		
FBPC0	0	100
FBPC1	10	90
FBPC2	30	70
FBPC3	50	50

Preparation of composites

The filling flours were dried to under 2% of moisture content. The filling flour and polymer were first pre-mixed with a mechanical blender (1200 rev.min-1) and then, homogenized with a rotary drum blender (30 to 40 rev.min-1 for 5 min). The prepared mixture was laid between two aluminum caul plate and pressed with a flat table hot-press machine (Cemil Usta SSP 125, Istanbul, Türkiye) for 15 min under a pressure of 2.3–2.5 N/mm^2 at 170°C. To prevent sticking of the mixture to the plates, wax paper was used in both sides. At the end of pressing time the panels were kept in the switched off hot press for cooling. The panels dimension were 500 × 500 × 4 mm.

Three panel were produced for each group. The target density of the panels was 1.0 g/cm^3. The panels were conditioned according to ASTM D618-21 (2021).

Testing procedures

Density, water absorption (WA) and volumetric swelling (VS) after 1 day, 3 days and 60 days water-soaking test, surface roughness test and glossiness tests were carried out to determine as physical properties of the produced panels. In addition, modulus of elasticity in bending (MOE), modulus of rupture (MOR), tensile strength were carried out to evaluate as mechanical properties of the panels. Mechanical tests were conducted with a universal testing machine (Marestek, Istanbul, Türkiye). Ten replications were tested for each group. Testing procedures were carried out according to related standarts that are given in Table 2.

Table 2. The standards used for some of technological properties in the study

Test	Standard
Density	ASTM D792 (2013)
Water absorption and thickness swelling	ASTM D570-98 (2018)
Surface roughness	DIN 4768 (1990)
Glossiness	Measured with Glossmeter at 20–60–85 degree
Modulus of elasticity in bending (MOE)	ASTM D790-17 (2017)
Modulus of rupture (MOR)	ASTM D790-17 (2017)
Tensile strength	ASTM D638-14 (2014)

Statistical analysis

The test results were evaluated statistically according to the analysis of variance (ANOVA) (SPSS, IBM Corporation, Version 22, Armonk, NY, USA).

Results and discussion

Density

The effect of terrestrial animal and fish bone flour content changes on the density of produced panels are shown in Table 3.

According to the table, values varied between 0.97 to 1.14 g/cm^3 for the panel that produced with terrestrial animal bone and 0.94 to 1.12 g/cm^3 for the fish bone. As can be seen from the table, density increases as both terrestrial animal and fish bone additive ratio increase.

Table 3. Density values

Sample		Density (g/cm³)
Control (PE)		0.96
Terrestial animal bone (%)	10	0.97
	30	1.05
	50	1.14
Fish bone (%)	10	0.94
	30	1.03
	50	1.12

Volumetric swelling (VS) and water absorption (WA)

The results related to effect of terrestrial animal and fish bone content changes on the VS and WA were investigated throughout 60 days test were given in Table 4.

Table 4. Results of volumetric swelling and water absorption (%)

Sample		Volumetric swelling			Water absorption		
		1 day	3 days	60 days	1 day	3 days	60 days
Control (PE)		0.00	0.00	0.56	0.13	0.30	1.07
Terrestial animal bone (%)	10	0.30	0.73	3.22	0.33	0.81	4.38
	30	0.65	0.65	3.66	0.65	1.40	4.77
	50	2.40	2.84	4.85	1.55	2.56	5.30
Fish bone (%)	10	0.87	1.01	0.99	0.38	0.55	5.05
	30	1.10	1.28	2.73	0.25	0.89	5.54
	50	3.82	4.45	3.45	2.09	3.35	6.07

It can be understood from the table that VS and WA values increase depend on both terrestrial animal and fish bone additive ratio and exposure time increased. As is well known, the polymers are hydrophobic and not effected by water molecules as can be seen control sample that was influenced very limitedly. The highest VS and WA values obtained from the panels that produced with 50% terrestrial animal and fish bone flour content. However, it is seen that values are very low when compared with some research that studied with wood-plastic composites (WPC) (Gezer et al., 2016; Durmaz, 2021).

Surface roughness (μm)

The results of surface roughness values were given in Table 5. In general, surface roughness values increase depend on both terrestrial animal and fish bone content ratio increase. The highest surface roughness values were obtained as 4.83 µm from the panel produced with 50% fish bone.

Table 5. Results of surface roughness

Sample		Mean			Standard deviation			Coefficient of variation (Cov)		
		Ra	Rz	Rq	Ra	Rz	Rq	Ra	Rz	Rq
Control (PE)		3.24	19.81	4.01	0.52	2.40	0.46	16.16	12.12	11.51
Terrastial animal bone (%)	10	3.09	18.75	4.07	0.67	3.56	0.74	21.79	18.99	18.12
	30	4.35	24.72	5.43	0.79	3.53	0.63	18.21	14.30	11.52
	50	4.24	25.15	5.52	0.41	2.49	0.44	9.78	9.91	8.05
Fish bone (%)	10	4.05	21.93	5.23	0.53	3.15	0.73	13.11	14.36	13.94
	30	4.17	23.32	5.26	0.70	4.37	0.84	16.69	18.72	16.03
	50	4.83	30.81	6.40	0.81	3.20	1.50	16.86	10.39	23.37

The surface roughness is related with particle size of the content. It is thought that the reason for the increasing surface roughness is the particle size of the used as bone flour in this study. Therefore, the surface roughness may reduced by using smaller particle size of bone additive in the content of the panels.

Glossiness (Gu)

The results of glossiness test values at 60° incidence angle were presented in Table 6. Glossiness is an important factor for the aesthetic and appearance of the material. The lowest glossiness value was obtained from control sample while the highest values were obtained from the panel produced with 10% terrestrial animal and fish bone content.

Table 6. Results of glossiness

Sample		Mean (60°)	Standard deviation	Coefficient of variation (Cov)
Control (PE)		3.76	0.49	12.91
Terrastial animal bone (%)	10	4.78	0.50	10.39
	30	4.29	0.67	15.58
	50	4.50	1.00	22.24
Fish bone (%)	10	4.76	1.29	27.17
	30	4.68	1.57	33.44
	50	4.33	1.41	32.52

Modulus of rupture (MOR)

The results of modulus of rupture test were given in Table 7. The highest value was obtained from control group with 48.45 N/mm^2 while the lowest value was obtained with 12.21 N/mm^2 from the panel produced with 50% fish bone content.

Table 7. Results of modulus of rupture (MOR) (N/mm^2)

Sample		Mean	Standard deviation	Coefficient of variation (Cov)
Control (PE)		48.45	2.09	4.31
Terrastial animal bone (%)	10	36.49	2.88	7.89
	30	17.57	3.13	17.83
	50	13.79	2.00	14.53
Fish bone (%)	10	37.80	2.08	5.51
	30	21.27	3.76	17.70
	50	12.21	1.30	10.60

It can be seen from the table that values were decreased as both terrestrial animal and fish bone content increased. In comparison to similar research in the literature that studied with WPC (Durmaz, 2021; Avci, 2012; Avci et al., 2014) MOR values are very low.

Modulus of elasticity (MOE)

The results of MOE test were presented in Table 8. The highest value was obtained from control group with 1683.98 N/mm^2 while the lowest value was obtained with 1381.4 N/mm^2 from the panel produced with 50% terrestrial animal bone content.

Table 8. Results of modulus of elasticity (MOE) (N/mm^2)

Sample		Mean	Standard deviation	Coefficient of variation (Cov)
Control (PE)		1 683.98	127.29	7.56
Terrastial animal bone (%)	10	1 529.09	168.30	11.01
	30	1 413.11	292.68	20.71
	50	1 381.40	176.68	12.79
Fish bone (%)	10	1 561.44	101.89	6.53
	30	1 594.98	75.73	4.75
	50	1 401.72	243.30	17.36

In general, values were decreased as both terrestrial animal and fish bone content increased. In comparison to similar research in the literature that studied with WPC (Durmaz, 2021; Avci, 2012; Avci et al., 2014) MOE values are very low.

Tensile strength

The results of tensile strength test were shown in Table 9. The highest value was obtained from control group with 26.95 N/mm^2 while the lowest value was obtained with 2.8 N/mm^2 from the panel produced with 50% fish bone content.

Table 9. Results of tensile strength (N/mm^2)

Sample		Mean	Standard deviation	Coefficient of variation (Cov)
Control (PE)		26.95	5.43	20.15
Terrastial animal bone (%)	10	10.43	2.20	21.08
	30	6.59	1.50	22.72
	50	5.25	0.71	13.58
Fish bone (%)	10	11.66	2.95	25.32
	30	6.06	0.99	16.40
	50	2.80	0.53	19.08

According to the table, it can be said that a considerable decrease were realized in tensile strength of the materials. Additionally, values were decreased as both terrestrial animal and fish bone content increased. As a reason, it is thought that there were not realized enough strong bond structure between polymer and terrestrial animal and fish bone flour. In comparison to similar research in the literature that studied with WPC (Durmaz, 2021; Avci, 2012; Avci et al., 2014) MOE values are very low.

Conclusions

This study was aimed to investigate usability of terrestrial animal and fish bone waste in production of polymer composites. For this purpose, composite boards were produced by mixing the materials as chip form into high density polyethylene (HDPE) polymer homogeneously at the rate of 10–30–50% by weight. Density, VS and WA, surface roughness and glossiness properties were investigated as physical properties, MOR, MOE and tensile strength properties were investigated as mechanical properties of the produced panels.

According to the results, despite VS and WA test samples exposure to water for 60 days, results were given considerable lower results in comparison with some of referenced WPC values. Accordingly, it can be said that the panels may suitable to use in application which required water resistance. For the surface roughness and glossiness, as the additive ratio of both terrestrial and fish bone content increased, values for surface roughness increased and glossiness were decreased. In case of required low surface roughness and high glossiness values, particle size may use in smaller sizes that used in this study.

On the side of mechanical properties, in general, MOR and MOE values were considerable decreased as additive ratio of the terrestrial animal and fish bone increased within the mixtures. Similar situation were realized in tensile strength values as well. When the results were compared with some referenced WPC results, it was seen that MOR and MOE values are very low especially in tensile strength.

As a result of this study, it can be said that the produced panels may be suitable to use for the area of water resistance but non-load bearing required. More research may be carried out to develop mechanical properties by using coupling agents and reinforced materials.

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