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Study on the Mechanical Properties of Water Hyacinth Fiber Reinforced High Density Polyethylene Composite

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Abstract

Natural fibers have recently gained attention due to low environmental impact, biodegradability, low cost and easy availability. In this research work, water hyacinth (WH) fiber was used as reinforcement in the fabrication of the natural fiber composites. WH plant fiber reinforced high-density polyethylene (HDPE) thermoplastic composites were fabricated by compression molding process. Fabrication parameters such as water hyacinth content, alkali treatment concentration, treatment time and coupling agent amount were varied in three levels and composites specimens were fabricated according to Taguchi's L9 orthogonal array. Grey Relation Analysis (GRA) was used to optimize the fabrication parameters. The results showed that the increase in WH fiber volume fraction, NaOH concentrations and treatment time increased the tensile and flexural strength of the composite up to some point and after that, it decreased. However, the strength of the composite was found to decrease with the increase of NaOH concentration and decrease of coupling agent concentration. ANOVA analysis revealed that the water hyacinth particle content had the highest contribution to tensile and flexural strength, followed by coupling agent dosage, treatment time, and NaOH concentration in order. Mechanical properties were optimized when the WH/HDPE composite fabricated with 30% water hyacinth fiber treated with 5wt% NaOH concentration for 12 hours and mixed with 15% coupling agent. The simultaneous effects of fabrication parameters on tensile and flexural strength of the WH/HDPE composites were studied. The fabricated WH/ HDP composite can be used as a viable alternative material for making furniture, ceiling, tile and partition boards.

Keywords: Natural Fiber, Water Hyacinth, High Density Polyethylene, Taguchi method, Grey Relational Grade Analysis

Introduction

Natural fiber reinforced composites have received much attention nowadays, due to the increase in pollution and environmental threats of synthetic fiber reinforced composites. Natural fiber-reinforced composites have many advantages as they are abundantly available in nature, lightweight, biodegradable, renewable, economical, environmentally friendly, and have reasonable strength and stiffness. Different types of natural fibers namely, flax, hemp, jute straw, wood, rice husk, wheat, palm, sisal, coir, water hyacinth, banana fiber, pineapple leaf fiber, and papyrus were investigated for composite fabrication (Faruk et al., 2012) Among the natural fibers, water hyacinth (WH) (*Eichhornia Crassiper*) fiber is found to have good mechanical and thermal properties (Ajithram et al., 2021). It has a great potential to be used as a filler material in polymeric composites because of its high cellulose content (Bolenz et al., 1990; Kumar et al., 2009). Many researchers have been carried out in which WH fibers as reinforcement in different thermoplastics and thermosetting matrices, especially with low-density polyethylene (LPDE), polyester, polypropylene (PP), epoxy resin and High-density polyethylene (HDPE) matrices.

Properties of WH fiber reinforced polymers composites are influenced by various factors such as amount of fiber content, fiber orientation, chemical treatment of fiber, treatment time and type of coupling agent, fiber extraction method, type of matrix material, composite fabrication method and so on.

Mechanical properties of WH reinforced polymer composites were significantly affected by fiber concentration. Water Hyacinth Fiber / Polyester composites prepared from 5 to 10 wt% of fiber yielded the best properties (Ramirez et al., 2015). Fiber concentration also affects the thermal stability of WH/HDPE composites. The decomposition temperature of the composites decreased with the increase of fibre content due to the poor chemical reaction between WHF and the matrix (Wirawan et al., 2013). In addition to fiber concentration, orientation of WH fiber also affects the mechanical properties. Tensile strength of WH fiber reinforced biobased epoxy composite was influenced by the fiber orientations (Sumrith, & Dangtungee, 2019).

A chemical treatment of WH fiber was performed for removing certain amounts of lignin, wax and oils coatings on the surface of the fiber. This helps to produce a rough fiber surface (Oushabi et al., 2017; Wong et al., 2010). This improves the wetting of the matrix material on the fiber surface and enhances interfacial adhesion between the fibers and matrix, which are essential for the production of stronger composites. Chemical modification of water hyacinth fibers with poly(methyl methacrylate) before the fabrication of LDPE/NR/WH composite increased the mechanical and thermal properties. It was also observed that the chemical modification of fiber increased percentage crystallinity and elongation at break (Supri et al., 2011). Alkaline treatment with NaOH increased the moisture absorption of the fiber by damaging the cellulosic structure at walls of WH fiber. However, higher concentration of NaOH found to decrease the mechanical properties of the composites due to the cellulosic structure damage (Abral et al., 2013; Abral et al., 2014). Increase in concentration of NaOH up to 20%, increased the thermal stability of WHF/HDPE composite (Sutrisno et al., 2013). Higher concentration of alkali solution chemically attacked the fiber wall and removed more hemicelluloses which have lowed thermal stability. This attributed to the overall increase of thermal stability of the composite. Chemical treatment of WH fibers with benzenediazonium salt solution improved the compatibility between the WH fibers and polypropylene matrix (Saha et al., 2018).

Coupling agents are substances that are used in small quantities to treat the fiber surface so that bonding occurs between the hydrophilic fibers and the hydrophobic polymer matrix (Chun & Woodhams, 1984; Dalväg et al., 1985). Use of coupling agent enhanced mechanical properties, thermal properties and water absorption resistance of WH fiber reinforced LDPE/composites. Coupling agents namely NCO-Polyol (Supri et al., 2010), Polyethylene-grafted-maleic anhydride (PE-g-MAH) (Tan et al., 2013) and Polyaniline (PANI) (Supri et al., 2014) and Isophorone diisocyanate-polyhydroxyl (Supri & Ismail, 2011) were used by researchers in the LDPE matrix based WH fiber composites. PE-g-MAH coupling agent was also used in the fabrication of recycled high-density polyethylene/water hyacinth fiber (rHDPE/WHF) composites. Inclusion of PE-g-MAH in rHDPE/WHF resulted in higher tensile strength, higher Young’s modulus and lower water absorption. Better fiber dispersion and less fiber pull was also achieved with 6 wt% of PE-g-MAH. (Tan et al., 2015).

From the literature review, it was observed that many researchers have conducted investigations on water hyacinth fiber reinforced polymer composites with different matrices such as LPDE, polyester, polypropylene (PP) and epoxy resin. To increase the fiber strength, the fibers were treated with many types of treatment chemicals. In addition to this, the coupling agents are to improve its stiffness and interfacial adhesion with the matrix. Few researchers ventured in to study the effects of different fabrication parameters on the properties of water hyacinth (WH) reinforced HDPE composites. In addition to this, the effects of alkali treatment concentration, treatment time and the amount of coupling agent were not considered by any researchers. In many literatures, these factors were assumed to be constant for optimizing other process parameters.

Hence, in this research work, an attempt is made to fabricate water hyacinth fiber reinforced high-density polyethylene (WH/HDPE) thermoplastic composites. This work also investigates the effects of fabrication parameters such as volume fraction of WH fiber, concentration of NaOH, volume fraction of coupling agent and treatment time on the mechanical properties of WH/HDPE composites. These parameters were varied in three levels and composites specimens were fabricated according to Taguchi's L9 orthogonal array. Analysis of variance (ANOVA) was performed to determine the percentage contribution and significant of these parameters and Grey Relation Analysis was used to optimize the fabrication parameters for maximizing the mechanical properties of the WH/HDPE composite.

Materials and Methods

Materials used

Recycled high-density polyethylene (rHDPE) was selected as the matrix material. It has a very low moisture absorption level and could solve the fast degradation problems of natural fiber, thus improving the natural fiber's performance in a wet environment (Lei et al., (2007). Recycled high-density polyethylene (rHDPE) pellets obtained from a local shop was used in this research work and is shown in Figure 1(a).

(a) (b)

Figure 1. Raw materials used in the fabrication of water hyacinth reinforced HDPE (a) recycled HDPE, (b) WH fiber

Water hyacinth fiber extraction was done by drying process (Ajithram et al., 2021). The leaves and roots were removed to get the stem of WH plant. After washing away the dirt from the stem with water rinsing, it was chopped into small pieces of size in the range of 3 to 4 cm. Then the chopped stem pieces were allowed to dry under the sun to remove the moisture content for 24 hours. Dried pieces of WH were treated with 3 liter alkaline solution for a specified period of time. Alkaline solution was prepared by mixing NaOH in water to the required weight concentrations. After this chemical treatment, chopped pieces of WH stem were washed with fresh distilled water for completely removing the residuals of alkaline solution in the WH stem and then dried in an open atmosphere under. Finally, the dried pieces of WH stem were ground into powder, which is referred to as WH fibers, hereafter in this paper. Fiber obtained from Water hyacinth plant (*Eichhornia Crassipes*) as shown in Figure 1(b) was used as the reinforcement material in this research work. Water hyacinth plant was selected because of the availability of this plant in abundance at Lake Tana in Amhara Region of Ethiopia (Asmare, 2017; Gezie et al., 2018). Furthermore, water hyacinth fiber has better mechanical and thermal properties as well as low density compared to other natural fibers (Ajithram et al., 2021). In this study, coconut oil was used as a coupling agent (Husseinsyah et al., 2016). This forms a bridge of chemical bonds between the fiber and matrix.

Selection of fabrication parameters and orthogonal array

In this study, fiber volume fraction, concentration of NaOH, treatment time and coupling agent concentration were selected as fabrication parameters and the effects of these parameters on the mechanical properties of the WH/HDPE composite were investigated. These four parameters were examined at three levels as shown in Table 1. Taguchi experimental design according to the L_9 (3^4) orthogonal array shown in Table 2 was selected for this investigation.

Table 1. Fabrication parameters and their levels

Parameter designation	Parameters	Levels		
		1	**2**	**3**
A	WH fiber volume fraction (v%)	20	30	40
B	Concentration of NaOH (w/v%)	5	10	15
C	Treatment Time (Hour)	6	12	24
D	Coupling agent volume fraction (v%)	5	10	15

Table 2. Experimental design using L9 (3^4) Orthogonal Array

Experiment run	Levels of parameter settings			
	Fiber volume fraction (v%) (A)	**Concentration of NaOH (w/v%) (B)**	**Treatment time (Hrs) (C)**	**Coupling agent volume fraction (v%) (D)**
1	20	5	6	5
2	20	10	12	10
3	20	15	24	15
4	30	5	12	15
5	30	10	24	5
6	30	15	6	10
7	40	5	24	10
8	40	10	6	15
9	40	15	12	5

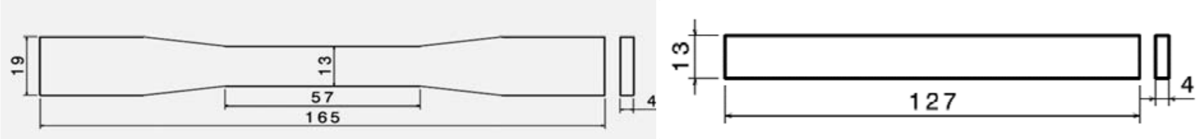
Composite fabrication process

In each experimental run, WH/HDPE composite was fabricated by setting the parameters according to the L_9 (3^4) orthogonal array. The metal mold of size 20 cm x18 cm x0.6 cm was used for the fabrication of composites. Mold filled with a homogeneous mixture of WH fiber and recycled

HDPE was placed inside the oven and heated to 180°C. After the melting of resin, the mold was taken out of the oven and compressed to compact the composite and to remove any trapped air. When the composite in the mold was dried, it was removed out of the mold.

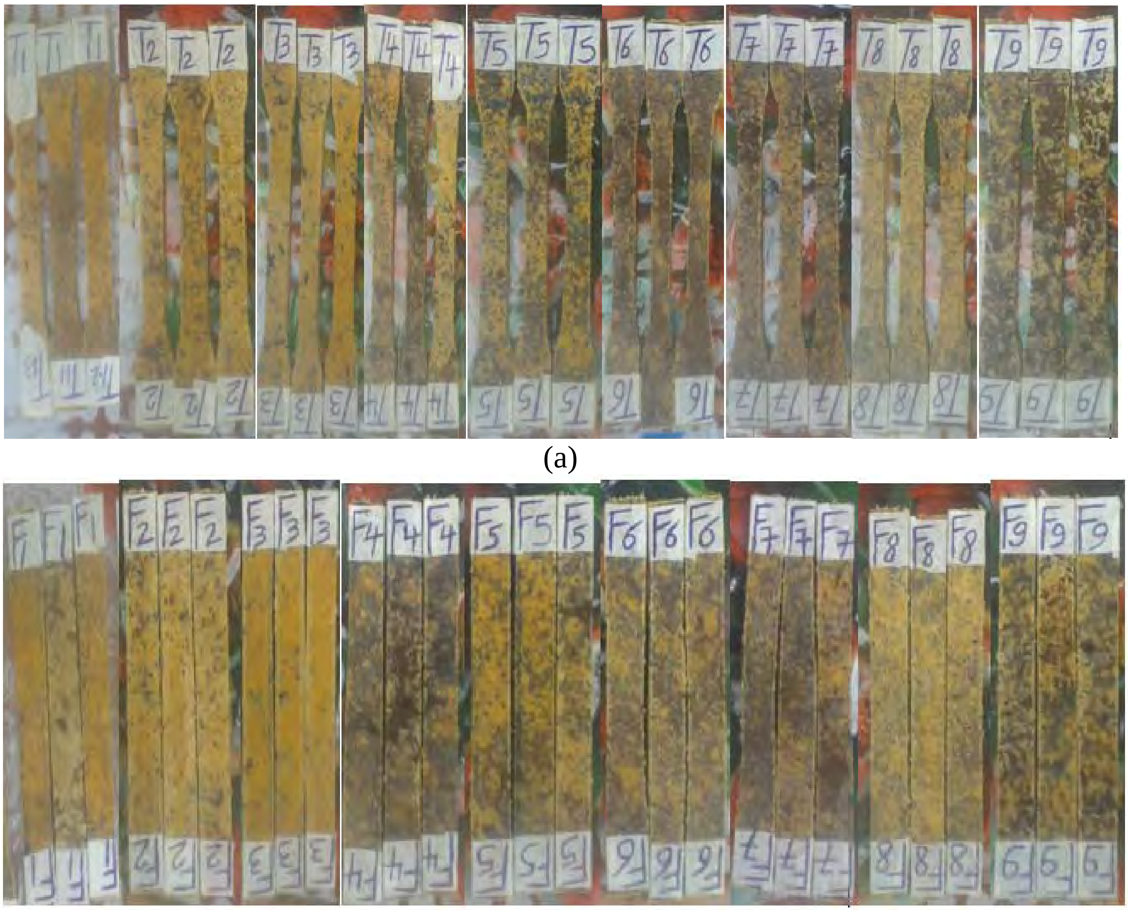
Measurement of response parameters

From each composite fabricated, three tensile test specimens and three flexural test specimens were cut according to ASTM standards D638 (ASTM D638-14, 2014) and D790 (ASTM Standard D 790-10, 2010) respectively. The dimensions of the tensile test specimen and flexural test specimen according to ASTM standards are presented in Figures 2 (a) and (b). Photographs of the prepared tensile and flexural tests are shown in Figures 3 (a) and (b). Tensile test and flexural tests were conducted using a universal testing machine (UTM) (Make: Gunt Hamburg, Model WP 310). The crosshead speed for the tensile test and flexural test were maintained at 5mm/min.



(a) (b)

Figure 2 (a) ASTM 638 standard tensile test specimen, (b) ASTM D 790 standard flexural test specimen



(a)

(b)

Figure 3 1Prepared WH /HDPE composite specimen for (a) Tensile Test and (b) Flexural test

Optimization Using Grey Relational Analysis

Grey Relation Analysis (GRA) was used in this study to optimize the fabrication parameters for maximizing the mechanical properties of the WH/HDPE composite. GRA was introduced by Professor Deng in 1982 for solving the problem involving multiple responses by translating them into a single response (Ganta et al., 2017) GRA starts with the normalization of each response ranging from 0 to 1. This process is known as gray relational generation. Then grey rational co-efficient (GRC) for the normalized values of each response are calculated. At last, the grey relational grade (GRG) is computed by taking the average grey relational coefficient (GRC) values corresponding to each experimental run. An experimental run with higher value of GRG indicates the optimum combination of process parameters for multi-objective responses. After the GRA analysis, the significance and percentage influence of fabrication parameters over the quality characteristics were estimated with analysis of variance (ANOVA).

Results and Discussions

Table 3 shows the experimental results for tensile strength and flexural strength of WH/HDPE composites. Figures 4 and 5 show the photographs of tensile test and flexural test specimens after fracture, respectively. Results were further processed for performing GRA analysis.

Table 3. Experimental results

Exp. run	Tensile strength(MPa)				Flexural strength (MPa)			
	Trial 1	Trial 2	Trial 3	Avg.	Trial 1	Trial 2	Trial 3	Avg.
1	25.36	25.40	25.28	25.35	27.69	28.62	28.38	28.23
2	25.95	25.83	25.85	25.88	33.23	32.77	32.31	32.77
3	24.43	24.69	25.11	24.74	31.85	32.31	31.38	31.85
4	28.92	29.46	28.11	28.83	36.46	36.92	35.54	36.31
5	26.46	26.42	26.85	26.58	33.69	32.77	32.31	32.92
6	28.15	28.42	27.12	27.90	33.23	32.77	32.31	32.77
7	23.81	23.23	24.12	23.72	30.92	32.31	31.38	31.54
8	25.69	25.65	25.62	25.65	35.08	36.00	34.15	35.08
9	24.65	25.23	24.50	24.79	31.85	32.31	31.38	31.85

Figure 4 Tensile test specimens of WH /HDPE composites after tensile test

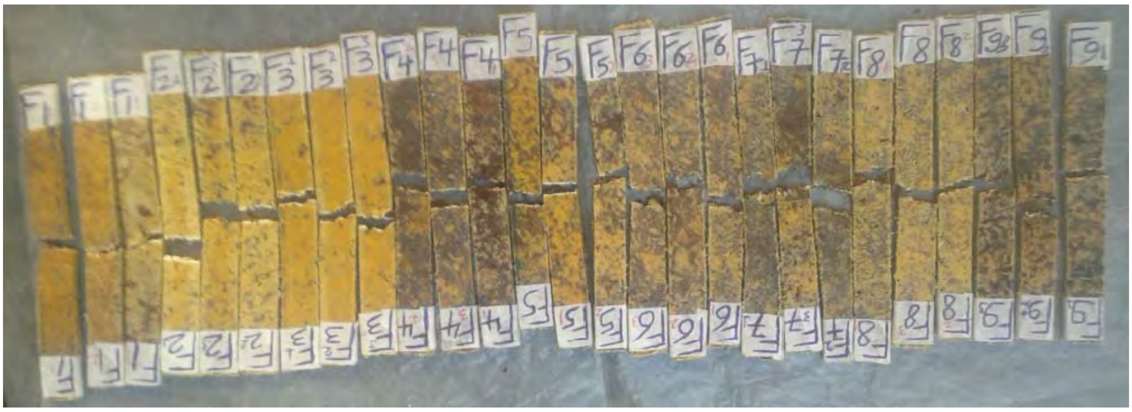


Figure 5. Flexural test specimens of WH /HDPE composites after flextural test

The normalized responses, deviation sequences, grey relational coefficients, calculated CRG and rank for each experimental run are tabulated in Table 4. It has been observed that experimental run 4 has the highest value of GRG, indicating the optimum combination of process parameters for multi-objective responses. Therefore, the optimal parameters settings of experiment run 4 (i.e., A2B1C2D3) are most likely the optimum for maximizing the tensile and flexural strength.

Table 4. Grey relational coefficients, grey relational grade and rank for each run

Exp. Run	Normalized value		Deviation sequences		Grey relational coefficients		Grey Relation Grade (GRG)	Rank
	Tensile strength (MPa)	Flexural strength (MPa)	Tensile strength (MPa)	Flexural strength (MPa)	Tensile strength (MPa)	Flexural strength (MPa)		
1	0.319	0.000	0.681	1.000	0.423	0.333	0.378	9
2	0.423	0.562	0.577	0.438	0.464	0.533	0.499	5
3	0.200	0.448	0.800	0.552	0.384	0.475	0.430	7
4	1.000	1.000	0.000	0.000	1.000	1.000	1.000	1
5	0.560	0.580	0.440	0.420	0.532	0.544	0.538	4
6	0.818	0.562	0.182	0.438	0.733	0.533	0.633	2
7	0.000	0.410	1.000	0.590	0.333	0.459	0.396	8
8	0.378	0.848	0.622	0.152	0.446	0.767	0.606	3
9	0.209	0.448	0.791	0.552	0.387	0.475	0.431	6

Table 5. Response table for grey relational grade

Level	Fiber volume fraction (v%)	Concentration of NaOH (w/v%)	Treatment Time (Hrs)	Coupling Agent concentration (v%)
1	0.4357	0.5913	0.5390	0.4490
2	0.7237	0.5477	0.6433	0.5093
3	0.4777	0.4980	0.4547	0.6787
Delta	0.2880	0.0933	0.1887	0.2297
Rank	1	4	3	2

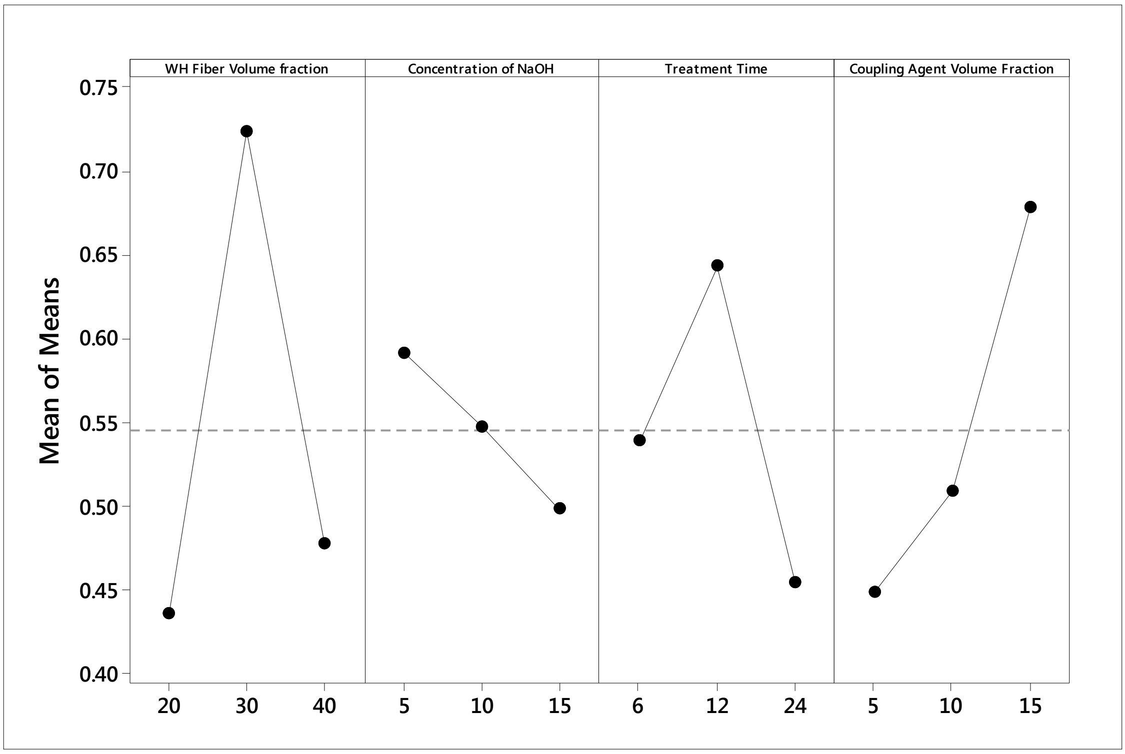


Figure 6. Main Effect plot for mean GRG

Table 5 shows the mean GRG values for each for each level of the process parameters and the same is graphically represented as the main effect plot as shown in Fig. 6. These results clearly indicate the relative effects of each process parameter on the response parameter and provide the optimal combination of process parameters for fabricating WH/HDPE composite with high tensile and flexural strength. It is observed that the tensile and flexural strength increases with WH fiber particle volume fraction up to 30% and then decreased by 40%. The results showed that as WH fiber content increased more, the tensile and flexural strength of HDPE/WF particle composites decreased due to poor adhesion between HDPE matrix and WH particles. When the fiber content increased, the fibers are not completely coated by the HDPE matrix (Schwarzkopf & Burnard, 2016). This resulted in clustering of fibers within the matrix and the formation of microcracks at the interface. All these above reasons are attributed to the reduction of tensile and flexural strength when there is an increase in fiber content.

The treatment of WH fibers with NaOH solution decreased the tensile and flexural strength when there was an increase in the concentration. The same effect was also observed with the increase in alkali treatment duration. This was due to the fact that more NaOH concentration and treatment duration damaged the chemical structure of cellulose where the cellulose molecular chains lose their crystalline structure and damages the fibers inter-laminar bonding which reduced the strength of the fibers (Abral et al., 2013). As the coupling agent concentration increases, the tensile and flexural strength of the composite also increase. This is because the increment coupling agent enhances the interface adhesion between the WH particle and HDPE matrix. This behavior was in agreement with the work done by Husseinsyah et al., (2016).

It was also found that WH fiber concentration is the most influencing fabrication parameter for achieving optimal tensile and flexural strength and is followed by the coupling agent concentration, treatment time and NaOH concentration in that order. The optimal process parameter setting for fabricating WH/HDPE is A2B1C2D3, i.e., fiber volume fraction= 30%, concentration of NaOH=5%, treatment time=12 Hrs and coupling agent concentration= 15%.

Using Minitab 18.1 software, Analysis of Variance (ANOVA) was performed to determine the relative significance of fabrication factors on the mechanical properties of WH/HDPE. The result of ANOVA for grey relational grade values is shown in Table 6. ANOVA analysis has been carried out for a level of significance of 0.1, i.e., for 90% level of confidence. As the degree of freedom for the error term is zero, F ratio cannot be calculated. Adjusted sum of squares was used to calculate percentage contribution. As the percentage contribution of NaOH concentration is 4.41% which is lower than 5%, it was treated as an insignificant factor and it was pooled. Pooling of this factor was done by combining the adjusted sum of square of this factor with that of error. The result of ANOVA analysis after pooling is shown in Table7

Table 6. AVOVA for GRG

Source	DF	Adj SS	Adj MS	F ratio	%Contribution
WH fiber volume fraction	2	0.14522	0.072612	*	48.90
NaOH concentration	2	0.01308	0.006542	*	4.41
Treatment time	2	0.05359	0.026796	*	18.05
Coupling agent concentration	2	0.08506	0.042530	*	28.64
Residual Error	0	*	*		*
Total	8	0.29696			100

Table 7. Pooled AVOVA for GRG

Source	DF	Adj SS	Adj MS	F value	%Contribution	Remark
WH fiber volume fraction	2	0.14522	0.072612	11.10	48.90	significant
NaOH concentration	[2]	0.01308	0.006542	pooled		
Treatment time	2	0.05359	0.026796	4.10	18.05	significant
Coupling agent concentration	2	0.08506	0.042530	6.50	28.64	significant
Residual Error	2	0.01308	0.006542		4.41	
Total	8	0.29696			100	

For 90% level of confidence, F value obtained from F- Table is 9.0 ($F_{0.1}$ (2, 2)). Therefore, the process parameters that have F value greater than 9 are significant. Accordingly, only WH fiber content was found to be significant. It is also observed that WH particle content has the highest contribution (48.90%) on tensile and flexural strength followed by coupling agent (28.64%), treatment time (18.05%), and NaOH concentration (4.41%).

Conclusions

In this present study, WHP/HDPE composite was successfully fabricated and experiments were conducted to assess the tensile and flexural strength of the prepared composites according to Taguchi's experimental design. Grey relational analysis was adapted to optimize the process parameters for achieving higher tensile and flexural strengths. Following are the conclusions obtained in this research work.

1. WH fiber content was the most influencing factor for tensile and flexural strength, followed by coupling agent dosage, treatment time, and NaOH concentration in sequence.
2. The tensile and flexural strength of the composite enhanced with the increase of the WH fiber content and alkali treatment duration to a certain limit and then decreases.
3. Strength of the composite was decreased with the increase of NaOH concentration and the coupling agent concentration.
4. Optimal mechanical properties of WHP/HDPE composites were obtained when the composites are fabricated with the combination of parameter levels A2B1C2D3, i.e., 30% (by volume fraction) water hyacinth fiber treated with 5% NaOH solution for 12 hours and mixed with 15% (by volume fraction) coupling agent.
5. Analysis of Variance (ANOVA) for GRG indicated that the WH particle content is majorly contributing to about 48.90%, followed by coupling agent (28.64%), treatment time (18.05%), and NaOH concentration (4.41%).

While this study makes a significant contribution to knowledge and fills the gap in the existing literature, it is not without its limitations. In this research work, the composite was fabricated with compression molding method. Further research may be carried out using other manufacturing processes such as extrusion and injection molding for analyzing their effects on the properties. Investigation of WHP composites for other functional properties such as hardness, impact strength and other mechanical properties of the composites materials could also be considered. Finally, other treatment chemicals such as silane, acetylation, sodium chlorite, sulfuric acids and the use of coupling agents such as maleic anhydride-polypropylene (MAPP), maleic anhydride grafted polyethylene (MA-g-PE) may also be considered in future work.

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References

Abral, H., Kadriadi, D., Rodianus, A., Mastariyanto, P., Arief, S., Sapuan, S.M. & Ishak, M.R. (2014). Mechanical properties of water hyacinth fibers – polyester composites before and after immersion in water. *Mater. Des*. 58, 125-129.

Abral, H., Putra, H., Sapuan, S.M. & Ishak, M.R. (2013). Effect of alkalization on mechanical properties of water hyacinth fibers-unsaturated polyester composites. *Polym. Plast. Technol. Eng*. 52(5), 446 – 451.

Ajithram, A., Jappes, J.W. & Brintha, N.C. (2021). Water hyacinth (Eichhornia crassipes) natural composite extraction methods and properties–A review. *Mater. Today*. 45(2), 1626-1632.

Ajithram, A., Jappes, J.W. & Siva I. (2021). Water Hyacinth (*Eichhornia Crassipes*) Natural Fiber Composite Properties—A Review. In: Mohan, S., Shankar S. and Rajeshkumar G. (Ed.). *Materials, Design, and Manufacturing for Sustainable Environment. Lecture Notes in Mechanical Engineering*. Springer, pp: 183-193.

Asmare, E. (2017). Current trend of water hyacinth expansion and its consequence on the fisheries around North Eastern Part of Lake Tana, Ethiopia. *J. Biodivers. Endanger Species*. 5, 189.

ASTM D638-14. (2014). *Standard Test Method for Tensile Properties of Plastics*, ASTM International, West Conshohocken, Pennsylvania, USA.

ASTM Standard D 790-10. (2010). S*tandard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials,* ASTM International, West Conshohocken, Pennsylvania, USA.

Bolenz, S., Omran, H. & Gierschner, K. (1990). Treatments of water hyacinth tissue to obtain useful products. *Biol. Wastes*. 33(4), 263-274.

Chun, I & Woodhams, R.T. (1984). Use of processing aids and coupling agents in mica-reinforced polypropylene. *Polym. Compos*. 5(4), 250-257.

Dalväg, H., Klason, C. & Strömvall, H.E. (1985). The efficiency of cellulosic fillers in common thermoplastics. Part II. Filling with processing aids and coupling agents. *Int. J. Polym. Mater*. 11(1), 9-38.

Faruk, O., Bledzki, A.K., Fink, H.P. & Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000–2010. *Prog. Polym. Sci*. 37(11), 1552-1596.

Ganta, V., Sagar, K.S. & Chakradhar, D. (2017). Multi objective optimisation of thermally enhanced machining parameters of Inconel 718 using grey relational analysis. *Int. J. Mach. Mach. Mater*. 19(1), 57-75.

Gezie, A., Assefa, W.W., Getnet, B., Anteneh, W., Dejen, E. & Mereta, S.T. (2018). Potential impacts of water hyacinth invasion and management on water quality and human health in Lake Tana watershed, Northwest Ethiopia. *Biol. Invasions*. 20, 2517–2534.

Husseinsyah, S., Seong Chun, K., Hadi, A. & Ahmad, R. (2016). Effect of filler loading and coconut oil coupling agent on properties of low-density polyethylene and palm kernel shell eco-composites. *J. Vinyl. Addit. Technol*. 22(3), 200-205.

Kumar, A., Singh, L.K. & Ghosh, S. (2009) Bioconversion of lignocellulosic fraction of water hyacinth (eichhornia crassipes) hemicellulose acid hydrolysate to ethanol by pichia stipitis. *Bioresour. Technol*. 100(13), 3293-3297.

Lei, Y., Wu, Q., Yao, F. & Xu, Y. (2007). Preparation and properties of recycled HDPE/natural fiber composites. Composites Part A: *Appl. Sci. Manuf*. 38(7), 1664-74.

Oushabi, A., Sair, S., Hassani, F.O., Abboud, Y., Tanane, O. & El Bouari, A. (2017). The effect of alkali treatment on mechanical, morphological and thermal properties of date palm fibers (DPFs): Study of the interface of DPF–Polyurethane composite. *S. Afr. J. Chem. Eng*. 23, 116-123.

Ramirez, N.F., Hernandez, Y.S., De Leon, J.C., Garcia, S.V., Lvova, L.D. & Gonzalez, L.G. (2015). Composites from water hyacinth (Eichhornea crassipe) and polyester resin. *Fibers Polym*. 16(1), 196-200.

Saha, M. & Afsar, A.M. (2018). Thermo-mechanical and morphological properties of water hyacinth reinforced polypropylene composites. *Int. J. Eng. Mater. Manuf*. 3(3), 151-161.

Schwarzkopf, M.J. & Burnard, M.D. (2016). Wood-plastic composites—Performance and environmental impacts. In: Kutnar, A. & Muthu S. (Eds.). *Environmental Impacts of Traditional and Innovative Forest-based Bioproducts. Environmental Footprints and Eco-design of Products and Processes*. Springer, Singapore, pp: 19-43.

Sumrith, N. & Dangtungee, R. (2019). Mechanical Properties of Water Hyacinth Fiber Reinforced Bio-Based Epoxy Composite. *Key Eng. Mater*. 818, 7–11.

Supri, A.G. & Ismail, H. (2011). The effect of isophorone diisocyanate-polyhydroxyl groups modified water hyacinth fibers (Eichhornia crassiper) on properties of low density polyethylene/acrylonitrile butadiene styrene (LDPE/ABS) composites. *Polym. Plast. Technol. Eng*. 50(2), 113 – 120.

Supri, A.G. & Ismail, H. (2010). The effect of NCO-polyol on the properties of lowdensity polyethylene/water hyacinth fiber (Eichhornia crassiper) composites. *Polym. Plast. Technol. Eng.* 49(8), 766–771.

Supri, A.G., Tan, S.J., Ismail, H. & Teh, P.L. (2011). Effect of poly (methyl methacrylate) modified water hyacinth fiber on properties of low density polyethylene/natural rubber/water hyacinth fiber composites. *Polym. Plast. Technol. Eng*. 50(9), 898 – 906.

Supri, A.G., Tan, S.J., Ismail, H. & Teh, P.L. (2014). Properties of (Low-density polyethylene)/(natural rubber)/(water hyacinth fiber) composites: The effect of polyaniline. *J. Vinyl. Addit. Technol*. 20(2), 122-130.

Sutrisno, H., Wirawan, R., Wibawa, B. & Permatasari, D. (2013). Differential Scanning Calorimetry of Alkali-Treated Water Hyacinth (Eichhornia Crassipes)/HDPE Composites. *Proc 9th Int Conf Compos Sci Technol (ICCST-9)*, 407.

Tan, S.J., Supri, A.G. & Chong, K.M. (2015). Properties of recycled high-density polyethylene/water hyacinth fiber composites: the effect of different concentration of compatibilizer. *Polym. Bull*. 72, 2019-2031.

Tan, S.J., Supri, A.G. & Teh, P.L. (2013). Effect of PE-g-MAH as Compatibilizer on Properties of LDPE/NR/WHF Composites. *Appl. Mech. Mater*. 284-287, 87-93.

Wirawan, R., Pasaribu, R. & Kholil, A. (2013). Thermogravimetric Analysis of Untreated Water Hyacinth (Eichhornia Crassipes)/HDPE Composites. Composite Science and Technology: 2020-Scientific and Technical Challenges, *Proc. 9th Int. Conf. Compos. Sci. Technol. (ICCST-9).* 418.

Wong, K.J., Yousif, B.F. & Low, K.O. (2010). Effects of alkali treatment on the interfacial adhesion of bamboo fibres. *Proc. Inst. Mech. Eng. Pt. L J. Mater. Des. Appl*. 224(3), 139-148.