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The Influence of Piezoelectric and Fin Material on Piezoelectric-mini wind turbine energy harvester

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ABSTRACT

A piezoelectric device is an energy harvester by converting mechanical deflection into electrical output voltage. This research was conducted using an experimental method, where the bluff body is equipped in a wind tunnel at an angle of 40º, and a mini wind turbine as a contact area to generate collisions on the piezoelectric material coated with fins. The independent variables in this study include ceramic and PVDF piezoelectric materials, various fin materials such as paper, plastic, and aluminum. The piezoelectric material and mini wind turbine were installed in the wind tunnel with a wind speed of 9 m/s. Output voltage measurement was conducted using a data acquisition system, with settings performed for 60 seconds. The test results showed that the highest voltage from ceramic piezoelectric material with plastic fin material was obtained at 10.37 volts. The results also showed that the highest voltage from the PVDF piezoelectric material was obtained at 0.387 volts with the use of plastic fin material. Ceramic has a higher output voltage generate than PVDF due to several factors such as the piezoelectric coefficient, dielectric constant, polarization, domain structure, and mechanical rigidity. The stiffer and stronger polarization led to more efficient charge displacement resulting in higher voltage output. The best performance of plastic fins is attributed to their higher flexibility and ability to generate more stable and impactful contact with the piezoelectric surface during wind-driven collisions

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1. INTRODUCTION

Energy harvesting is an activity to capture ambient energy sources and convert them into electrical energy. The devices with low energy consumption and wireless sensors are the example of energy harvesting applications. Piezoelectric as an energy harvester has attracted significant attention due to its high energy density, scalability, and compatibility with microelectromechanical systems (MEMS). The piezoelectric effect in a specific material can generate electric voltage when mechanical stress takes place, such as vibrations or oscillations [1], [2], [3]. Piezoelectric systems are lighter, more compact, and easier to integrate into environments than electromagnetic or electrostatic harvesters [4], [5], [6]

Recent studies have explored diverse designs and configurations to optimize piezoelectric energy harvesting. Researchers experiment enhancement the power output in low speed of wind with integrated galloping system, vortex-induced vibrations (VIV), and flutter phenomena [3], [5], [7], [8], [9]. The combination design of piezoelectric with triboelectric, electromagnetic, or electrostatic have shown potential for performance improvement [10], [11], [12]. Additionally, unique objects and mechanisms such as Y-shaped structures [3], micro windmill [13], [14], fluttering in triboelectric [15] and rotational harvester [6] have demonstrated the capabilities of piezoelectric energy harvester. The enhancement of circuit configuration [16], nonlinear mechanism [17], and environmental adaptability [18] has offering sustainable energy solutions. Based on previous research, the utilization of piezoelectric materials continues to be developed to generate energy that can be used in daily life. Therefore, researchers have employed piezoelectric materials using a hybrid wind turbine method to induce impact on the piezoelectric material. Consequently, further research is required to investigate the effects of varying piezoelectric material, piezoelectric quantity, and fin material on maximizing the electrical voltage output from piezoelectric energy harvesting. The objective of this study is to evaluate the influence of these parameters to identify the most efficient configuration for optimizing energy output.

2. METHOD

This study observes piezoelectric materials and fin materials to determine the effective measurement of electrical voltage from piezoelectric materials and fin materials. The research method involves a real-world setup in a wind tunnel equipped with a 40º angled bluff body and a mini wind turbine as a contact area to induce impact on the piezoelectric material coated with fins. The independent variables in this study are ceramic piezoelectric materials, PVDF piezoelectric materials, paper fins, plastic fins, and aluminum fins, with a wind speed of 9 m/s. The piezoelectric material and mini wind turbine are installed in the wind tunnel. Output voltage measurements are taken using a data acquisition system, with DataQ settings performed each lasting 20 seconds with 25 data in each second. Figures 1 and 2 illustrate the setup in the wind tunnel with the tilt of 40º bluff body, mini wind turbine, and fin-coated piezoelectric material.

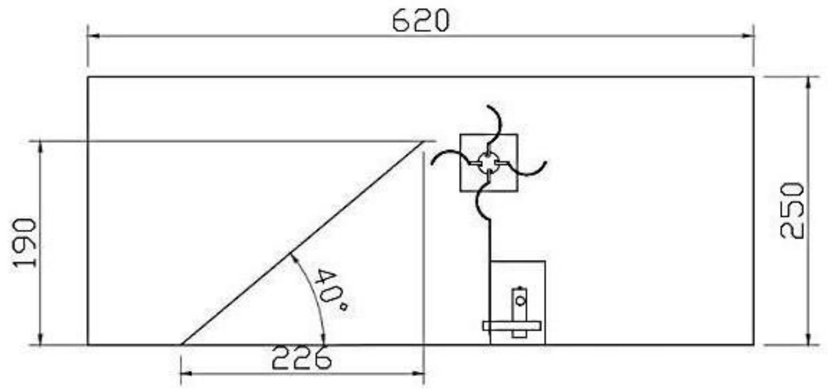
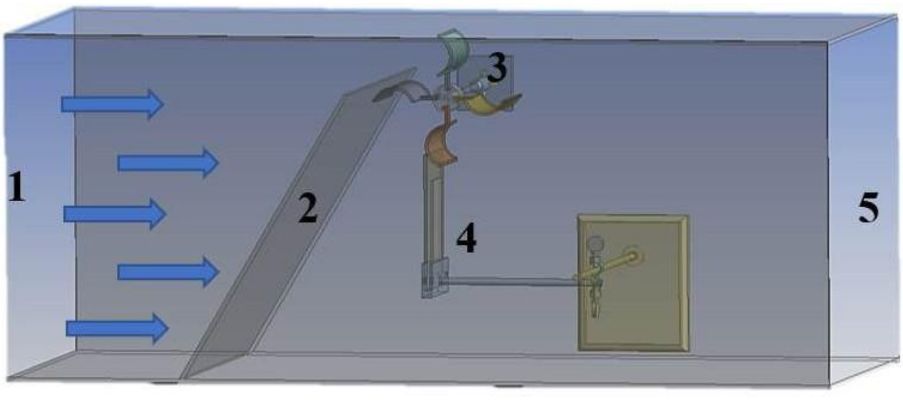


Figure 1. Top view of wind tunnel and mini wind turbine



Part
1. Wind inlet
2. Bluff body (40º tilt)
3. mini wind turbine
4. piezoelectric
5. wind outlet

Figure 2. Sensor and fin configuration

The piezoelectric materials used in this study are ceramic piezoelectric material (Type 1) and PVDF (type 2). The shape of ceramic piezoelectric is a rectangular prism, with dimensions of 80 mm in length, 40 mm in width, and 0.5 mm in thickness. The shape of PVDF material (with thick aluminum electrodes) is also rectangular prism but the dimensions are 140 mm in length, 20 mm in width, and 0.15 mm in thickness. All piezoelectric materials are coated with fin materials, including paper, plastic, and aluminum. The wind turbine used in this study is a horizontal axis type with 4 blades, having a total diameter of 100 mm and a blade width of 60 mm. The mini wind turbine is made of Polypropylene plastic. DataQ with reference model DI-245 is a data acquisition system used in this study, which utilizes computer software for data analysis, making it easier and more accurate.

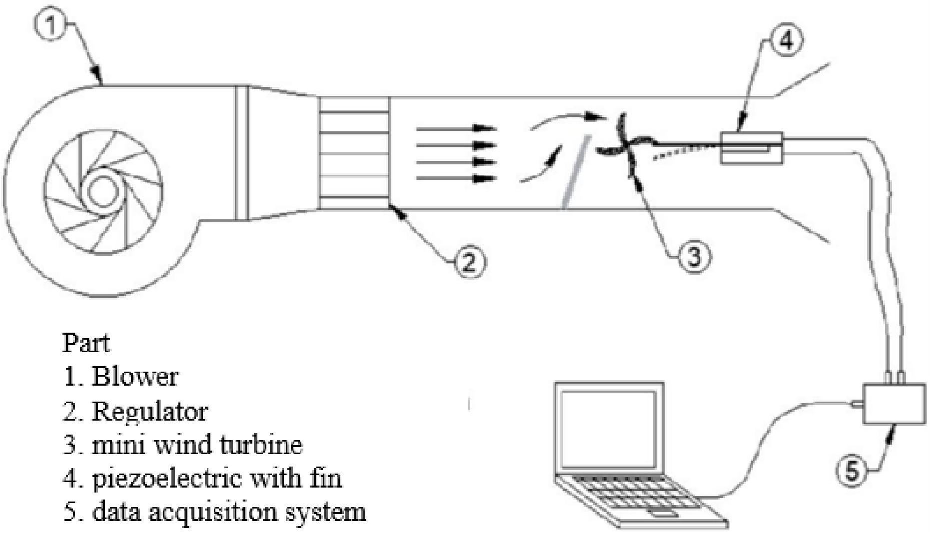


Figure 3. Experimental setup

3. RESULTS AND DISCUSSION

Result of voltage on the ceramic piezoelectric material with paper, plastic, and aluminum fin materials exhibit in Table 1. The highest electrical voltage output from the ceramic piezoelectric material testing was 10.37 volts, achieved using a plastic fin material at a wind speed of 9 m/s. It is stated that plastic is the most efficient fin material due to their flexibility. Plastics have stable structural in mechanical stress to transfer vibrational energy. The plastic fin demonstrated greater stability during impact with the wind turbine, and the collision between the wind turbine and the plastic fin did not cause damage to either the turbine or the piezoelectric material. The fin with aluminum material generated a moderate voltage output of 7.37 V. It due to the stiffness and weight of aluminum possible to reduces its fluttering amplitude or frequency under wind excitation, thus transferring less dynamic mechanical stress to the piezoelectric element. Paper is the lightest material in this experiment that generates low voltage. Light mass weight has difficulties transferring vibrational energy from turbine to piezoelectric element.

Table 1. Ceramic piezoelectric output voltage

Piezoelectric Material	Fin Material	Wind Speed (m/s)	Maximum Voltage (V)
Ceramic	Paper	9	5,98
Ceramic	Aluminum	9	7,37
Ceramic	Plastic	9	10,37

Overall, one of the crucial roles in the performance of piezoelectric energy harvesters is a fin material selection. The design of fin must accommodate a balance characteristic of material between stiffness for energy transfer and flexibility for oscillation. Among the materials tested, plastic emerged as the great material fin for enhancing energy conversion efficiency in ceramic-based piezoelectric harvesters.

Figure 4 presents the experimental results of ceramic piezoelectric material testing utilizing different fin materials. The generated voltage measurements were conducted using a data acquisition system. The observed negative voltage values indicate polarity reversal caused by oscillatory impacts, which is a characteristic response of piezoelectric materials subjected to alternating mechanical loads. The DataQ system was configured for a measurement duration each of 20 seconds.

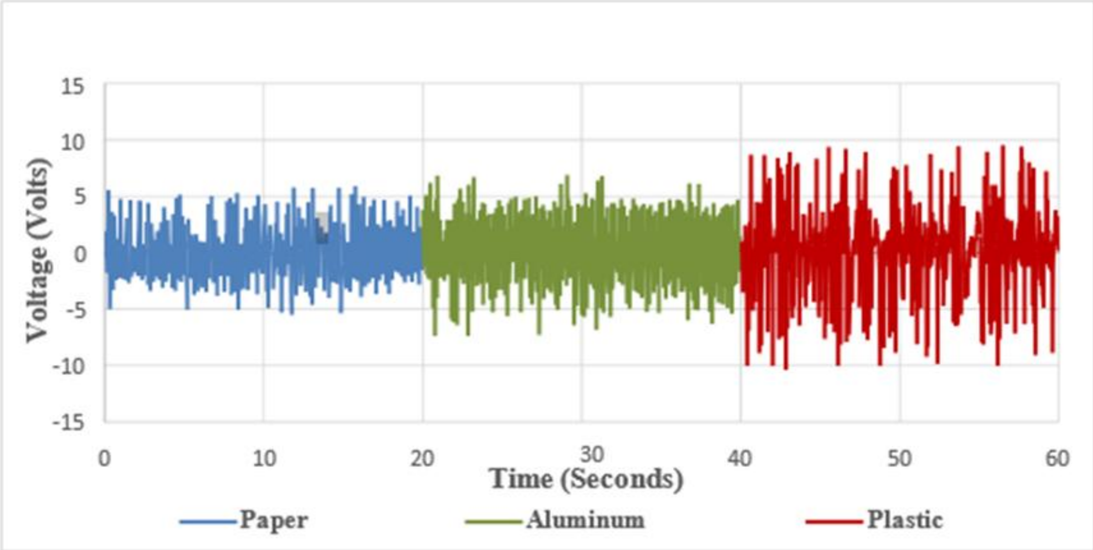


Figure 4. Voltage in various fin material in ceramic piezoelectric

The experimental results in Figure 4 exhibit significant results in output voltage depending on the fin material variation. Oscillating between -5V and +5V is a relatively low voltage that generated by paper fin due to the low of mass and structural flexibility. Aluminum fin generated voltage in range -8V to +8V, higher than paper fin. It's due to aluminum having higher stiffness and mass than paper fin that led to contribute deformation of the piezoelectric element. Plastic fin generated voltage in range -12V to +12V, it stated that plastic have the optimum fluttering under wind excitation and do the maximum conversion of kinetic energy to electrical.

Table 2. PVDF piezoelectric output voltage

Piezoelectric Material	**Fin Material**	**Wind Speed (m/s)**	**Maximum Voltage (V)**
PVDF	Paper	9	0,113
PVDF	Aluminum	9	0,235
PVDF	Plastic	9	0,387

Table 2 exhibits the material testing of PVDF piezoelectric with different fin material such as paper, plastic, and aluminum. The highest voltage generated from the PVDF piezoelectric material tested was 0.387 volts, achieved using a plastic fin material at a wind speed of 9 m/s. Plastic provides the dynamic interaction between wind flow and piezoelectric element. Its interaction led to balanced oscillation and enabling efficient transfer of vibrational energy. The highest electrical voltage result was obtained from the PVDF piezoelectric material with plastic fins at a wind speed of 9 m/s, due to the more intense and stable collision between the piezoelectric material and the plastic fins compared to paper and aluminum fins. The plastic fins were more stable during the collision with the wind turbine, and the collision did not cause damage to the wind turbine or the piezoelectric material.

Compare table 1 and table 2 show that ceramic is better performance in generate voltage than PVDF. It's due to several factors such as the piezoelectric coefficient, dielectric constant, polarization, domain structure, and mechanical rigidity. Piezoelectric coefficient is influencing the ability of conversion mechanical stress into electrical voltage. Dielectric constants enhance charge generation capability. Polarization leads to more efficient charge displacement under mechanical load. The domain structure in ceramics is engineered to maximize piezoelectric response, whereas PVDF, being a polymer, has a more flexible molecular arrangement that limits its voltage generation. Mechanical rigidity has correlation with stiffness, where the stiffer material can sustain greater mechanical stress without excessive deformation, resulting in higher voltage output.

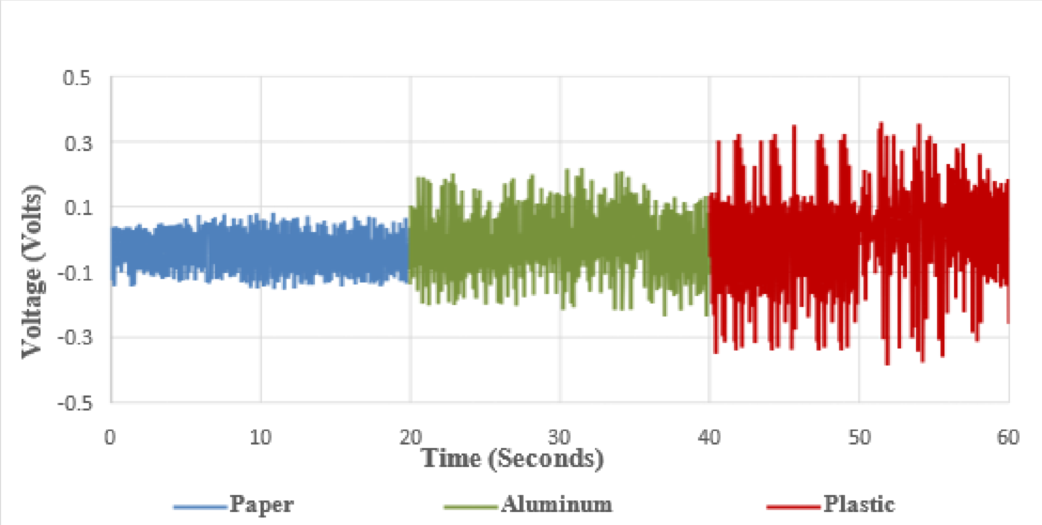


Figure 5. Voltage in various fin material in PVDF piezoelectric

Figure 5 illustrated the output voltage that generated in various fin material and PVDF Piezoelectric. Negative and positive values of voltage reflect the oscillation during deformation in piezoelectric element. Paper fin is the lowest output voltage but good in stable voltage fluctuation. This indicates that paper's low mass and high flexibility provides limited mechanical excitation to the PVDF layer. Aluminum fins demonstrated a broader voltage range, oscillating in range of -0.25V to +0.25V. It's due to higher stiffness than paper fin that enhances its interaction with airflow, resulting in more deformation of the piezoelectric element. Plastic fin generated the highest voltage in range of -0.4V to +0.4V due to the flexibility allowing great oscillations and high deformation.

4. CONCLUSION

This study has demonstrated the significant influence of both piezoelectric material type and fin material on the voltage output performance of piezoelectric energy harvesting. Two types of piezoelectric materials such as ceramic and PVDF were tested in various fin materials like paper, aluminum, and plastic. Experiment under a constant wind speed of 9 m/s in a wind tunnel environment. The findings revealed that the ceramic piezoelectric material produced the highest electrical output, reaching a maximum of 10.37 volts when paired with plastic fins. This performance is attributed to the flexibility of plastic which led to great oscillation and deformation in piezoelectric elements. Similarly, the PVDF piezoelectric material showed its best performance with plastic fins, achieving a peak voltage of 0.387 volts. Although the voltage output was lower than the ceramic counterpart, the pattern consistently showed that plastic fins facilitated more effective energy transfer across both material types. Aluminum fins generate moderate voltage levels, likely due to their higher stiffness than paper fins. The lowest voltages generated by paper fin due to insufficient structural mass and mechanical excitation. In conclusion, the plastic fin material consistently outperformed both aluminum and paper, making it the most suitable fin configuration for enhancing the output of piezoelectric energy harvesters. Furthermore, ceramic piezoelectric elements demonstrated greater potential for high-voltage applications, whereas PVDF materials offered more stable yet lower outputs. These insights contribute to the optimization of hybrid piezoelectric-wind energy harvesting systems, particularly in low-wind environments where material selection plays a critical role in maximizing energy output.

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REFERENCES

[1] D. G. Wakshume and M. Ł. Płaczek, "Optimizing Piezoelectric Energy Harvesting from Mechanical Vibration for Electrical Efficiency: A Comprehensive Review," *Electron.*, vol. 13, no. 5, 2024, doi: 10.3390/electronics13050987.

[2] S. Priya *et al.*, "A Review on Piezoelectric Energy Harvesting: Materials, Methods, and Circuits," *Energy Harvest. Syst.*, vol. 4, no. 1, pp. 3–39, 2019, doi: 10.1515/ehs-2016-0028.

[3] J. Wang, S. Zhou, Z. Zhang, and D. Yurchenko, "High-performance piezoelectric wind energy harvester with Y-shaped attachments," *Energy Convers. Manag.*, vol. 181, no. September 2018, pp. 645–652, 2019, doi: 10.1016/j.enconman.2018.12.034.

[4] Y. Zou *et al.*, "Advances in Self-powered Triboelectric Sensor toward Marine IoT," *Nano Energy*, vol. 122, no. November 2023, p. 109316, 2024, doi: 10.1016/j.nanoen.2024.109316.

[5] Y. Y. Lim, R. V. Padilla, A. Unger, R. Barraza, A. M. Thabet, and I. Izadgoshasb, "A self-tunable wind energy harvester utilising a piezoelectric cantilever beam with bluff body under transverse galloping for field deployment," *Energy Convers. Manag.*, vol. 245, p. 114559, 2021, doi: 10.1016/j.enconman.2021.114559.

[6] J. Zhang, Z. Fang, C. Shu, J. Zhang, Q. Zhang, and C. Li, "A rotational piezoelectric energy harvester for efficient wind energy harvesting," *Sensors Actuators, A Phys.*, vol. 262, pp. 123–129, 2017, doi: 10.1016/j.sna.2017.05.027.

[7] A. Gamayel, F. Mulyana, and B. W. Dionova, "Vortex-Induced Vibration of Triangular Bluff Body to Piezoelectric Energy Harvester in Laminar Flow," *AIP Conf. Proc.*, vol. 2578, no. November, 2022, doi: 10.1063/5.0106260.

[8] W. Sun, S. Jo, and J. Seok, "Development of the optimal bluff body for wind energy harvesting using the synergetic effect of coupled vortex induced vibration and galloping phenomena," *Int. J. Mech. Sci.*, vol. 156, no. November 2018, pp. 435–445, 2019, doi: 10.1016/j.ijmecsci.2019.04.019.

[9] V. R. Velusamy, F. M. Foong, N. A. R. Nik Mohd, and C. K. Thein, "Bistable dual cantilever flutter for potential wind energy harvesting applications," *Sustain. Energy Technol. Assessments*, vol. 63, no. January, p. 103637, 2024, doi: 10.1016/j.seta.2024.103637.

[10] Z. Duan *et al.*, "A wireless triboelectric sensing system with polygonal synchronous driven by bipolar electromagnetic generators for wide wind speed monitoring," *Sustain. Energy Technol. Assessments*, vol. 60, no. June, p. 103553, 2023, doi: 10.1016/j.seta.2023.103553.

[11] B. Vysotskyi, J. F. Ambia Campos, E. Lefeuvre, and A. Brenes, "Dynamic analysis of a novel two-sided nonlinear MEMS electrostatic energy harvester," *Mech. Syst. Signal Process.*, vol. 206, no. October 2023, p. 110932, 2024, doi: 10.1016/j.ymssp.2023.110932.

[12] V. Ordoñez, R. Arcos, and J. Romeu, "A high-performance electromagnetic vibration energy harvester based on ring magnets with Halbach configuration," *Energy Convers. Manag. X*, vol. 16, Dec. 2022, doi: 10.1016/j.ecmx.2022.100280.

[13] X. Du, M. Zhang, H. Chang, Y. Wang, and H. Yu, "Micro windmill piezoelectric energy harvester based on vortex-induced vibration in tunnel," *Energy*, vol. 238, p. 121734, 2022, doi: 10.1016/j.energy.2021.121734.

[14] A. Gamayel and A. Sunardi, "Performance of piezoelectric energy harvester with various ratio substrate and micro windmill," *Telkomnika (Telecommunication Comput. Electron. Control.*, vol. 22, no. 2, pp. 480–487, 2024, doi: 10.12928/TELKOMNIKA.v22i2.25691.

[15] W. Sun, Z. Ding, Z. Qin, F. Chu, and Q. Han, "Wind energy harvesting based on fluttering double-flag type triboelectric nanogenerators," *Nano Energy*, vol. 70, no. January, p. 104526, 2020, doi: 10.1016/j.nanoen.2020.104526.

[16] B. D. Truong, C. P. Le, and E. Halvorsen, "Analysis of MEMS electrostatic energy harvesters electrically configured as voltage multipliers," *AEU - Int. J. Electron. Commun.*, vol. 107, pp. 125–136, 2019, doi: 10.1016/j.aeue.2019.05.006.

[17] X. Guo, Y. Zhang, K. Fan, C. Lee, and F. Wang, "A comprehensive study of non-linear air damping and 'pull-in' effects on the electrostatic energy harvesters," *Energy Convers. Manag.*, vol. 203, no. November 2019, p. 112264, 2020, doi: 10.1016/j.enconman.2019.112264.

[18] J. Kan *et al.*, "Design, fabrication and characterization of a wind-isolated galloping energy harvester via an embedded piezoelectric transducer," *Mechatronics*, vol. 99, no. September 2023, p. 103147, 2024, doi: 10.1016/j.mechatronics.2024.103147.