Mechanical Characterization and Static Analysis of Natural Fiber Based Composite Propeller Blade

Nayak, Sunil
Mangalore Marine College and Technology

M. Prasanna Kumar
Visvesvaraya Technological University

https://doi.org/10.5109/6792832

出版情報：Evergreen. 10 (2), pp.805-812, 2023-06. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Mechanical Characterization and Static Analysis of Natural Fiber Based Composite Propeller Blade

Sunil Nayak[1*], M. Prasanna Kumar[2]
[1]Mangalore Marine College and Technology, Mangalore, Karnataka, India
[2]Visvesvaraya Technological University, Mysore, Karnataka, India

*Author to whom correspondence should be addressed:
E-mail:sunilnayak567@gmail.com

(Received April 5, 2023; Revised May 24, 2023; accepted June 6, 2023).

Abstract: This study is to examine the feasibility to make propeller blades intended for use in marine applications out of inexpensive, lightweight materials. Based on aberration, pliableness, perseverance, strain intensity packed up threshold, accessibility, and diaphanousness. Mechanical characterization of basalt fibre/epoxy was investigated. The results revealed that composite with 60% reinforcement exhibited with optimum mechanical property. The static analysis conducted to examine the advantages of composite materials for propellers in the marine industry, Epoxy/Basalt fibre is a fantastic invention. Epoxy/basalt fibre propeller with 60% reinforcement resulted in a lightweight propeller as contrasted to contemporary metal alloy propeller.

Keywords: Composite Material, Marine application, Material properties, Static structural, Propeller, Basalt fibre.

1. Introduction

A crucial and intricate component needed for the arbitrary hydrodynamic intensities and coercion during submerged thruster is the propeller blade. Standard metallic components are typically used in propeller blade construction due to high yield potency and dependability. Besides the metallic blades have indigent acoustical dampening attributes, which can result in term of noise from structural resonance, oxidation, pitting degradation, and endurance rupture. Propeller attainment is crucial since it influences the machinery's overall effectiveness[1]. Fixed pitch propellers (FPP) and Controllable pitch propellers (CPP) are the two kinds of propellers utilized in vessels on a professional basis. When compared to fixed pitch propellers, which have static pitch and thicken as they move from the boss to the blade tip, controllable pitch propellers (CPP) have a changeable pitch. The front and rear of rotor are fixed in place, rotor pitch is consistent during each round. Such features set it apart from a standard screw propeller. The cycloidal propellers become more susceptible to loading fluctuations because of the aforementioned factors[2]. The vessel travels ahead because every motion does have an identical and inverse response, resulting in the rotor generates a pressure gradient on the front and back edge of the propeller and accelerates fluid behind the rotors. The interior propeller geometry is affected by the pressure gradient, which results in the development of the dynamic and static stresses as well as a deformation of the propeller blades[3]. The crank shaft, interim rod, and its supports, as well as the stern tube wheel and its bearings, all provide rotary movement that is used to transfer thrust to drive the vessel. The blade itself then completes the rotating motion chain. A variety of naval constructions are now being created employing composite materials to improve operating efficiency while lowering maintenance costs. Composites possess capability to significantly lower procurement and life-cycle expenditures while also improving ship reliability and effectiveness. Several different naval constructions are now being explored employing fibre in forced polymer composites. The necessity to improve effectiveness and efficiency is motivated this advancement. Composites have a tremendous deal of capability in today's harsh environmental circumstances. The composite shows enhanced wear behaviors nearly to 60% over a prolonged time frame in a diversified condition, including adhesive, abrasive, and erosive[4]. Utilizing the nano fillers improves the mechanical and tribological characteristics as well as the bonding between the fibres and the matrix[5-9]. Composites are captivating because to their light weight, relatively inexpensive, great oxidation resistance, and outstanding hardenability[10-11]. Preponderance of these innovative tasks was influenced by the desire to combat issues with corrosion that metallic materials faced[12]. During 1950s these composite structures begin to install in the ship and submarines with the length less than 15 m, while lengths have continuously risen over time, all composite naval ships may now reach lengths of 90 meters. The structural weight of naval craft made up of composite material approximately 10% lighter than aluminum and 36% lighter than steel. The feasibility of exploring the potential of composites in superstructure, advanced mast system, bulkheads, decks, propellers, valves, heat exchangers, propulsion shafts, rudders, pipes and ducts[13]. Marine facilities and industries suffer from maritime biofouling. It is effective to control biofouling by using coatings with biocide release and nonbiocide release properties[14]. It is important for manufacturer to have a thorough understanding of how their actions affect the environment in order to improve their practises in the face of stringent and harsher environmental regulations. Considering that environmental regulations are the primary force behind the watercraft construction sector[15]. Presuming differing interfacial slip rates between the normal propeller and the propellers covered with the hydrophobic substance, it may be said that the propellers treated with the hydrophobic material are effective[16]. Weight curtailment is still important, especially for the top side weight of commercial ships. Vessels and its structures are particularly vulnerable to damage by salt and corrosive sea water. The use of thermoset composites in particular element can diminish serviceability due to the capacity of composites to withstand oxidation and endurance. The most popular type of reinforcing material used in maritime applications remains E-glass fibre, which offers elevated tensile strength and ultimate tensile strain in addition to great protection to dampness and chemical abrasion. Glass cannot compare to the strength and rigidity of carbon fibre. The composite of a carbon fibre in addition with other fibre have a capability to enhance the tensile and flexural characteristics[17]. Yet the price of these fibres is far more than the price of glass fibres, structures composed completely of carbon fibre are not inexpensive, and ship designers are finding the usage of hybrid laminates to be quite alluring[18]. Whenever the friction and wear are significant, many manufacturers try to substitute the standard materials in the vehicles with biodegradable ones[19]. The manufacturers have often placed a high priority on the creation of novel materials that meet market demands, and experts have accomplished the task of finding alternatives to the traditional materials to meet the needs of their customers[20]. Due the strength and rigidity, availability, recyclability, and disintegrate, natural fibres have the capability to be employed as reinforcement in composite materials[21]. The fibre treatment enhances the bonding between the reinforcement and matrix[22]. Basalt fibre is a natural fibre obtained by melting volcanic igneous basalt rocks. Basalt fibre is referred to as the "Non pollutant and ecofriendly substance of the twenty-first century" These natural fibres are exceptionally strong mechanically, chemically diverse, extremely abrasion resistant, and cost-effective. Basalt fibre has been recognized as a possible replacement material to address the cost and effectiveness constraints of conventional composites materials because it provides enhanced results that are equivalent to S-glass fibre and superior to E-glass fibre. In terms of tensile properties, basalt fibre is comparable to glass fibre and has a higher working temperature than both glass and carbon fibre. It is suitable for usage in difficult environments because to its outstanding usefulness temperature and chemical barrier properties. The pace at which molten lava cools has a significant impact on the micro structural components of basalt rock. Basalt fibres can survive a pH of nearly to 13 or 14, making them resistant to an alkaline environment, but they are less stable in strong acids. Moisture regains and basalt fibre moisture content is less than 1%[23]. These natural fibres provide strong intransigence to deterioration by chemicals, dampness absorption, in both acidic and alkaline conditions. Basalt fibre retains superior mechanical qualities in oxidative medium than glass fibre[24].

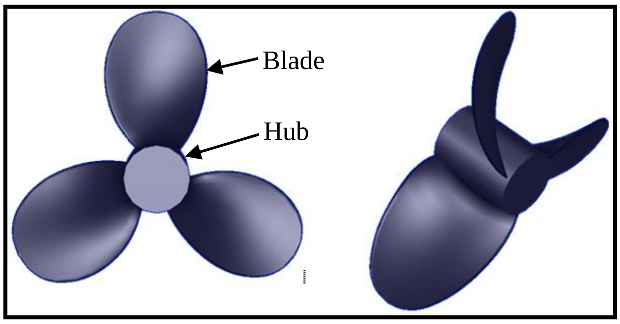


Fig.1: Propeller blade assembly details

In order to investigate the possibility for maritime rotor use, a FRP composite rotor blade has been constructed utilising a particular closed moulding created for hand lay-up approach[25]. The analysis on a modeled marine propeller that meets a given need while managing the effects of several factors[26]. The designed rotor is mathematically broken down using the framework approach and ANSYS. Compiled and analyzed the deformation, stress, and strain results for both composite and metallic propellers. The approach of hand layup was used to prepare the blade. ANSYS was used to do a numerical investigation to look at the deformation and stress influences under the static loading condition. According to their findings, when produced composite rotors were fastened with hub together instead of epoxy adhesive bonding, stress localisation and delamination were increased. The lightweight and more advantageous composite rotors are superior to traditional metallic propellers[27].

2. Materials and methodology

One of a maritime vehicle's essential parts is its propeller. Typically, rotor blades are made of metallic materials. Epoxy is employed as the matrix phase in the current investigation, with basalt fibre serving as reinforcement.

2.1 Selection of composite material

- Basalt fibre (Bi directional woven fabric)
- Epoxy resin
- Hardener
- Mould releasing agent (PVA).

The parameters of the matrix phase and reinforcing phase are displayed in Tables 1 and 2, respectively, below.

Table 1. Properties of Basalt fibre.

Properties	Values
Tensile Strength (Gpa)	4.84
Modulus of Elasticity (Gpa)	93.1
Elongation at Break (%)	3.15
Density (g/cm^3)	2.7

Table 2. Properties of Epoxy resin.

Properties	Values
Tensile Strength (Mpa)	75
Modulus of Elasticity (Gpa)	4.5
Specific strength (Mpa)	36
Pot life at 20^0 C	2 hrs

Along with the preference of matrix and reinforcement, the composite's production process plays a significant role in determining the material's final properties[28]. Hand layup methodology is adapted for fabrication for specimen with the dimension of 300 x 300 x 4 mm. The fabricated panels were cut to the required dimension. Stacking up the layers in the mould alternately and matrix was deposited at the same time. The process of lying down as the matrix with reinforcement in the

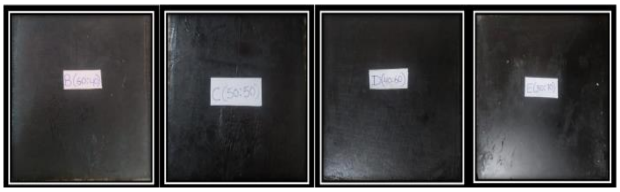


Fig.2: Fabricated composite laminates

Table 3. Composition of composite material.

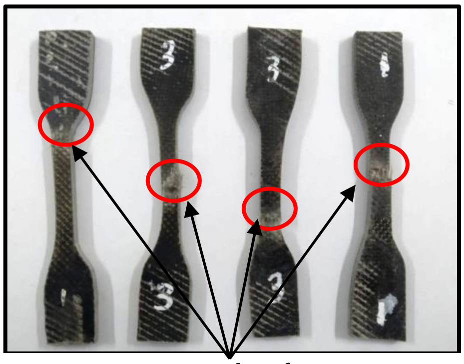
Sample name	Reinforcement		Matrix (wt%)
	Basalt fibre (wt%)	Layers	
B (S1)	60%	18	40%
C(S2)	50%	15	50%
D(S3)	40%	12	60%
E(S4)	30%	09	70%

mould with die is kept inside the hot hydraulic press machine at pressure of 100 bar with temperature of 700 ^oC. Allow the specimen to cure adequately in the hot press machine for 24 hours.

3. Mechanical characterization

3.1 Tensile test

The Tensile test is carried on Mecmesin MultiTest-xt UTM with capacity of with 10 kN. To determination of the tensile behavior of reinforced polymers in the form of dog bone shaped test specimens with Universal Testing Machine according to ASTM D638 standard.



Fractured surfaces

Fig.3: Tensile specimens

The five test samples are examined for every result before the mean is determined. Figure 3 displays the Load versus Displacement plot of the collected results.

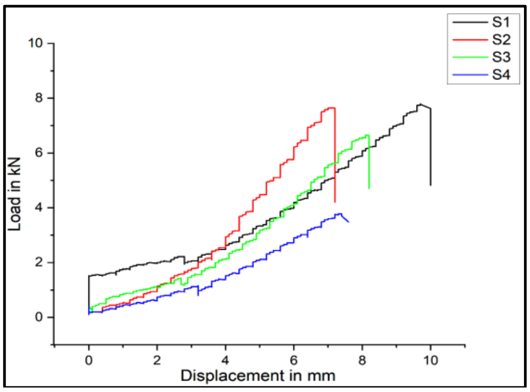
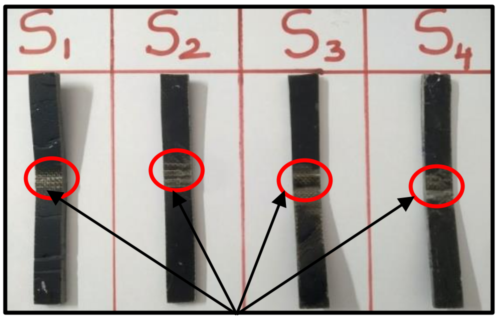


Fig.4: Load vs displacement graph for tensile specimen

The 60BF:40E (S1) specimen has higher young's modulus and ultimate strength, whereas 30BF:70E (S4) reinforced composites exhibit the lowest young's modulus and ultimate values. It is observed that the tensile properties gradually increasing when the basalt fibre percentage increase from 30% to 60% and this in turn will increase the resistance to crack propagation by the bonding effect. The tensile strength of the fabricated composite material decreases by decreasing the percentage of basalt fibre as reinforcement[24].

3.2 Flexural test

The flexural test (3-Point Bending) has been conducted by using bending test fixtures on computerized UTM. The specimen is set up as per ASTM D790 standard.



Fractured surfaces

Fig.5: Flexural test specimens

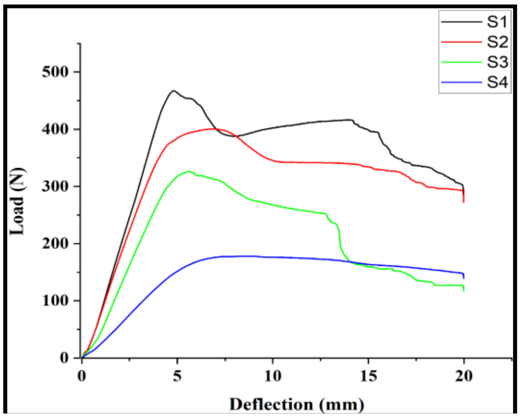
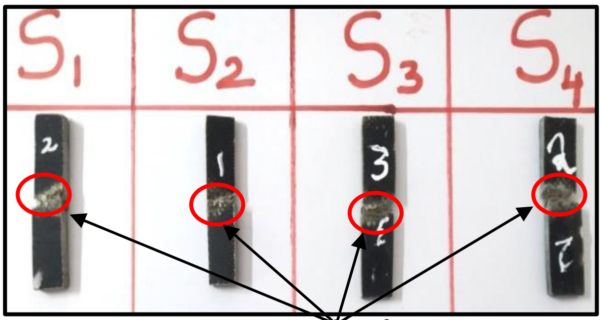


Fig.6: Load vs displacement graph for flexural specimen

The specimens with the greatest Maximum load and UFS values are 60BF:40E (S1) reinforced composites, whereas those with the lowest Young's modulus and Ultimate Tensile Strength are composites reinforced with 30BF:70E (S2). The enhancement obtained in flexural strength ascertains the compatibility of basalt fibre with epoxy. Basalt fibre has the more load bearing capacity when compared with other reinforcements used in composite. The presence of basalt fibre at upholds the interfacial bond among epoxy. For every increasing of fibre content there is a significant increase in flexural strength and modulus[7].

3.3 Impact test

As per ASTM D256, the impact energy is investigated using an un-notched Izod impact test. A pendulum is used to shatter an unnotched sample that is 60mm long, 12.5mm wide, and 4 mm thick. The sample is placed in a cantilever posture. Using a dial indicator which is mounted on the machine, the impact energy is computed. For every testing, five samples were collected and the results are averaged.



Fractured surfaces

Fig.7: Impact specimens

The highest Maximum impact strength observed in 60BF:40E (S1) specimen and the lowest impact strength observed in 30BF:70E (S4) specimen. Impact strength gradually increasing when the fibre percentage is increases. Consequently, more energy may be required for de-bonding the fibres. The improvement in impact strength of composite with the use of compatibiliser can be attribute to the improved fibre matrix interface between basalt fibre and epoxy matrix[11].

The Impact strength v/s Composition graph for the specimens with 60% fibre content, 50% fibre content, 40% fibre content, and 30% fibre content.

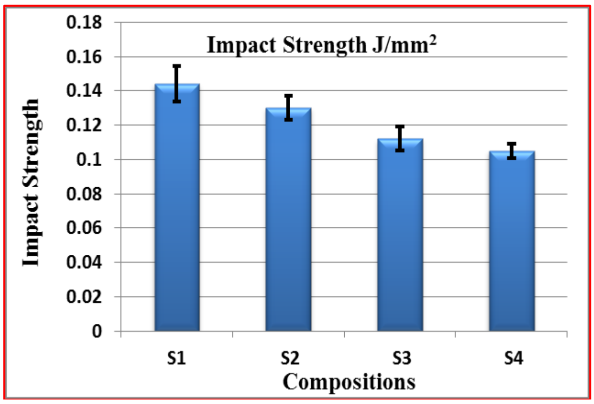


Fig.8: Impact strength vs Compositions

3.4 Water absorption test

Absorption of moisture from the atmosphere, there is a possibility of changing its specification which causes misalignment[23].

It is advisable to think about how water dispersion affects the constituent specimens in order to fully comprehend the impact of moisture absorption on the selected composite materials. As compared to other compositions, the sample made from the composition 60BF:40E (S1) exhibited the highest level of water retention. Figure 9 shows different water absorption sample differences.

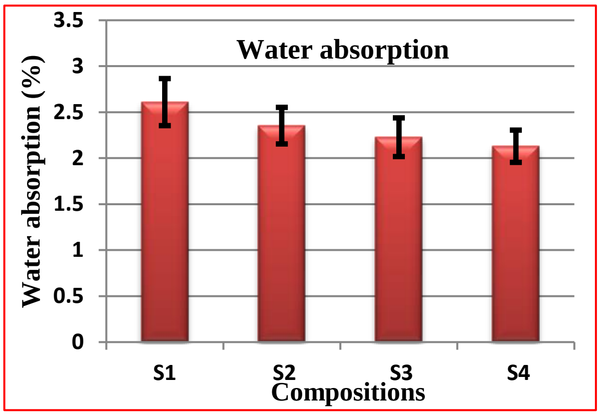


Fig.9: Water absorption vs Compositions

4. Static analysis

4.1 Specification of propeller

The parameters focused during propeller modeling research are, getting the lowest power needs, the least amount of pitting, disturbance, resonance, and the highest level of effectiveness at a suitable rotation[29]. Given the importance to the complexity[30-31], composite propeller blades needed extremely precise manufacturing execution to withstand variational hydrodynamic forces and pressure while submerged drive. The Wageningen blade from the B-Series is more commonly employed on commercial ships. The B-Series blade has a fairly basic form. Such propeller's portion is contemporary, and it performs well. B-Series blades often come in a variety. The variables were used in design of the 3 blade propeller of right hand operation with the 1.15 pitch to diameter ratio and 37088 mm^2 of total blade area.

4.2 Specification of propeller

The finite element programme ANSYS workbench was utilised for the numerical study of the blade. Both the skin and the spar of a blade are made of the composite material. Hexahedral shell elements were used to mesh all of the model's components (SHELL 181).

4.3 Meshing

Optimum mesh in which the element size for all four parts of the body was set. The numbers of elements are 46296 and the numbers of nodes are 10409.

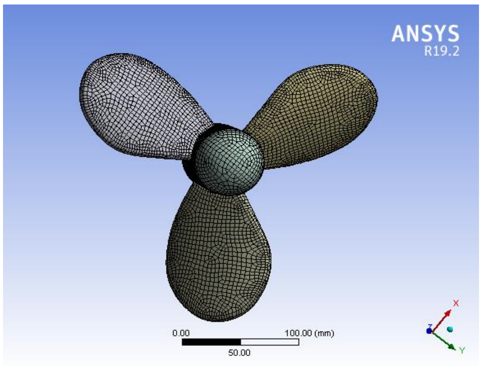


Fig.10: Fine meshed model of propeller

4.4 Boundary conditions

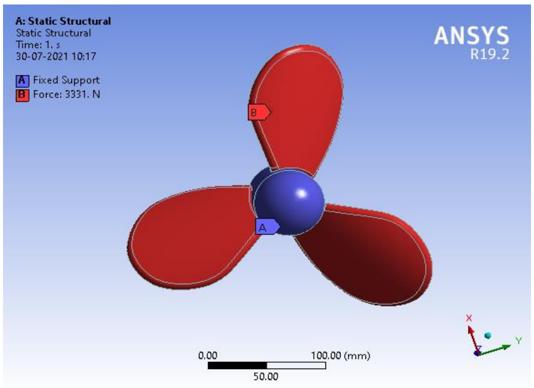


Fig.11: Boundary conditions with applied load =3331 N

Prior to solving, the boundary parameters were established. A hub is connected to a three-bladed propeller. The sites of contact between the blade and hub remained constant, and a thrust force of 3331 N was applied to the blades.

Table 4. Properties of Basalt/Epoxy material.

Properties	Values
Tensile modulus (E_x)	37700 MPa
Tensile modulus (E_y)	5237 MPa
Tensile modulus (E_z)	5237 MPa
Poisson ratio (ν_{xy})	0.2
Poisson ratio (ν_{yz})	0.21
Poisson ratio (ν_{zx})	0.21
Shear modulus (G_{xy})	2050 MPa
Shear modulus (G_{yz})	3630 MPa
Shear modulus (G_{zx})	3630 MPa

4.5 Composite propeller Static Structural Analysis

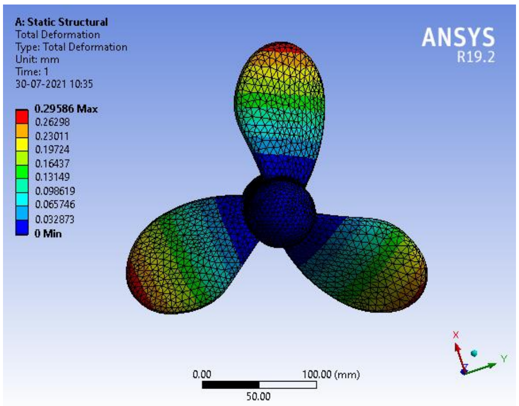


Fig.12: Composite propeller total deformation

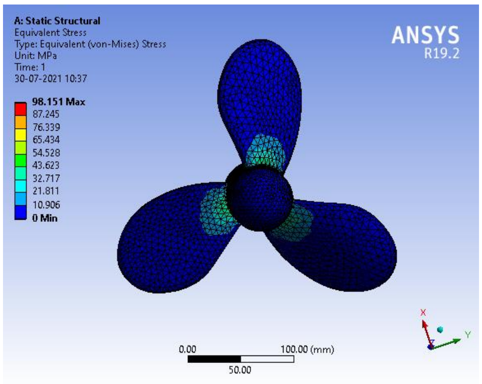


Fig.13: Composite propeller equivalent stress

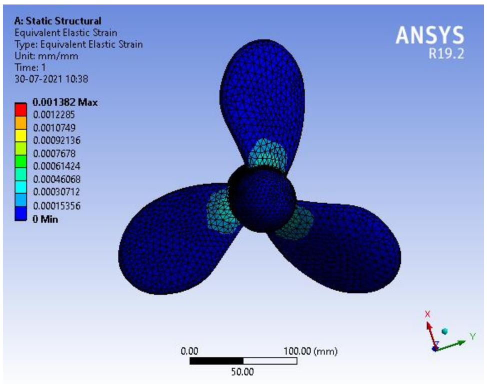


Fig.14: Composite propeller elastic strain

4.6 Metallic propeller Static Structural Analysis

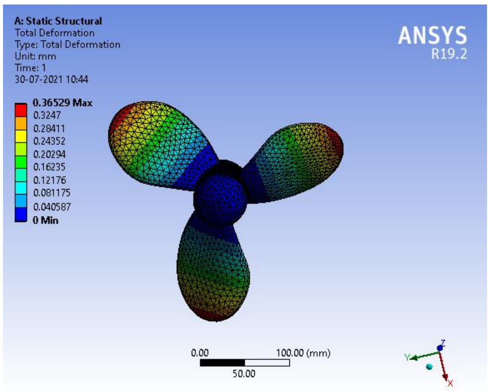


Fig.15: Metallic propeller total deformation

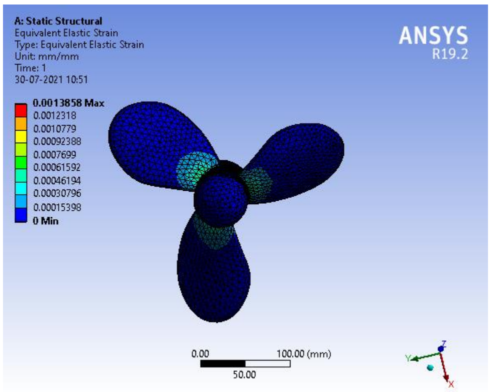


Fig.16: Metallic propeller equivalent stress

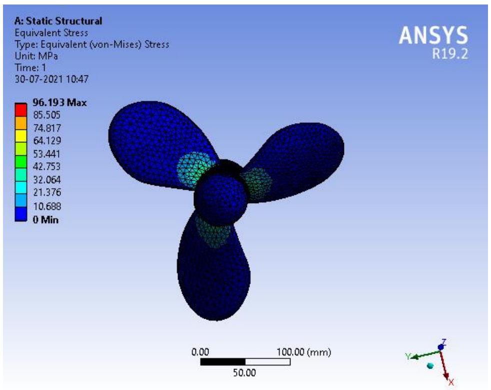


Fig.17: Metallic propeller elastic strain

Hub, that becomes 60 mm in diameter, exhibits the minimal deformation, while a endpoint of the blade exhibits the most deformity. The maximum stress is recorded toward the region where the propeller and hub mate. Between the blade's centre and the hub, there is an extremely low. Highest strain is present towards the propeller and hub meet. In between hub and the centre of the propeller, a very low value is found.

4. Conclusions

The experimental and numerical analysis was performed on fabricated composite specimens and the following conclusions are drawn based on the observations. The present work infers that 60BF:40E (S1 specimen) yields best ratio.

- Flexural, tensile and impact properties are better for 60BF:40E (S1 specimen) composition.
- The 30BF:70E (S4) specimen shows that least water absorption property with 2.1%.
- Use of Epoxy/Basalt fiber (60%:40%) leads to 20% weight decrease in propeller when compared with metallic propeller.
- The numerical results show the good agreement with experimental results for optimum composition (60BF:40E).

References

1) Yue Tan, Jing Li, Yuan Li and Chunbao Liu, “Improved Performance Prediction of Marine Propeller: Numerical Investigation and Experimental Verification,” *Mathematical Problems in Engineering*, **2019** 1-10 (2019). doi.org/10.1155/2019/7501524.
2) J. Joseph Prabhu, Anil Kumar Dash, Vishwanath Nagarajan and Mohammed Rabius Sunny, “Vibration analysis of cycloidal propeller blade during ship maneuvering,” *Journal of Marine Science and Technology*, **28** 44–71 (2023). doi.org/10.1007/s00773-022-00899-1.
3) Mohammed K. Khashan, Amjed AL-Khateeb, Ali H. Mutaib and Essam O. Al-Zaini, “Influence of Increasing Number of Blades on The Internal Structure of Hydro Propeller,” *International Journal of Mechanical Engineering and Technology*, **9** *(10)* 1434–1443 (2018).
4) Anis Adilah Abu Talib, Aidah Jumahat, Mohammad Jawaid, Napisah Sapiai and Alcides Lopes Leao, “Effect of Wear Conditions, Parameters and Sliding Motions on Tribological Characteristics of Basalt and Glass Fibre Reinforced Epoxy Composites,” *Materials*, **14** 701 (2021). doi.org/10.3390/ma14030701.
5) Davood Toorchi, Esmaeil Tohidlou and Hamed Khosrav, “Enhanced flexural and tribological properties of basalt fiber-epoxy composite using nano-zirconia/grapheneoxide hybrid system,” *Journal of Industrial Textiles*, **51** *(2S)* 3238S–3252S (2020). DOI: 10.1177/1528083720920573.
6) B. S. Kanthraju and B. Suresha, “Enhancement of Mechanical Properties and Wear Resistance of Epoxy: Glass Fiber, Basalt Fiber, Polytetrafluoroethylene and Graphite”, *Indian Journal of Advances in Chemical Science*, **S1** 107-113 (2016).
7) Prasanna S M, Dr. H R Vitala, T. Madhusudhan, and Dr. Raju B R, “Evaluation of Mechanical and Tribological Characterization of Glass-Basalt Hybrid Composites”, *International Journal of Engineering Research and Advanced Technology*, 02 *(01)* 27-34 (2016).
8) Anand Chelliah, “Mechanical Properties and Abrasive Wear of Different Weight Percentage of TiC Filled Basalt Fabric Reinforced Epoxy Composites,” *Materials Research*, **22** *(2)*: e20180431 (2018). dx.doi.org/10.1590/1980-5373-MR-2018-0431.
9) Ajith G Joshi, M. Prasanna Kumar and S. Basavarajappa, “Influence of Al_2O_3 Filler on Slurry Erosion Behavior of Glass/Epoxy Composites,” *Materials Science*, **5** 863 – 872 (2014). doi: 10.1016/j.mspro.2014.07.372.
10) C Anand Chairman, B Thirumaran, S P Kumaresh Babu and M Ravichandran, “Two-body abrasives wear behavior of woven basalt fabric reinforced epoxy and polyester composites”, *Materials Research Express*, **7** 035307 (2020). doi.org/10.1088/2053-1591/ab7de9.
11) Kalmeshwar Ullegaddi, Mahesha C.R and Shivarudraiah, “Tribological Properties of Basalt Fibers - A Review,” *Material Science Forum*, **969** 335–342 (2019). doi.org/10.4028/www.scientific.net/msf.969.335.
12) Rong Chai, Weiwei Zhu, Qian Li, Haohao Zou, Ying Han, Yu Zhao and Xu Ran, “Effect of Basalt Fiber Content on Mechanical and Tribological Properties of Copper-Matrix Composites,” *Metals*, **12** 1925 (2022). doi.org/10.3390/met12111925.
13) A.P. Mouritz, E. Gellert, P. Burchill and K. Challis, “Review of advanced composite structures for naval ships and submarines,” *Composite Structures*, **53** 2l–4l (2001).
14) Peng Hu, Qingyi Xie, Chunfeng Ma and Guangzhao Zhang, “Silicone-Based Fouling-Release Coatings for Marine Antifouling,” *American Chemical Society*, **36** *(9)* 2170-2183 (2020). doi.org/10.1021/acs.langmuir.9b03926.
15) Agis G. Koumentakos, “Developments in Electric and Green Marine Ships,” *Applied System Innovation*, **2** *(4)* 34 (2019). doi.org/10.3390/asi2040034.
16) Huachen Pan, Ran Zeng, Xiaoqing Tian, Elias Taalab, Ming Lv and Zefei Zhu, “Performance of a Propeller Coated with Hydrophobic Material,” *Journal of Marine Science and Engineering*, **10** *(2)* 236. doi.org/10.3390/jmse10020236.
17) H. Sosiati, N.D.M. Yuniar, D. Saputra, and S. Hamdan, “The Influence of Carbon Fiber Content on the Tensile, Flexural, and Thermal Properties of the Sisal/PMMA Composites,” *Evergreen Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **9** *(1)* 32-40 (2022). doi.org/10.5109/4774214.

18) Felice Rubino, Antonio Nisticò, Fausto Tucci and Pierpaolo Carlone, "Marine Application of Fiber Reinforced Composites: A Review," *Journal of Marine Science and Engineering*, **8** 26 (2020). doi.org/10.3390/jmse8010026.
19) Emad Omrani, Pradeep L. Menezes and Pradeep K. Rohatgi. "State of the art on tribological behavior of polymer matrix composites reinforced with natural fibers in the green materials world," *Engineering Science and Technology, an International Journal*, **19** 717–736 (2016). http://dx.doi.org/10.1016/j.jestch.2015.10.007.
20) Manoj Kumar Gupta, Vishesh Singhal and Nitesh Singh Rajput, "Applications and Challenges of Carbon-fibres reinforced Composites: A Review," *Evergreen Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **9** *(3)* 682-693 (2022). doi.org/10.5109/4843099.
21) Dody Ariawan, Wahyu Purwo Raharjo, Kuncoro Diharjo, Wijang Wisnu Raharjo and Bambang Kusharjanta, "Influence of Tropical Climate Exposure on the Mechanical Properties of rHDPE Composites reinforced by Zalacca Midrib Fibers," *Evergreen Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **9** *(3)* 662-672 (2022). doi.org/10.5109/4842526.
22) Veronica Ordonez, Haci Baykara, Ariel Riofrio, Mauricio Cornejo and Ricardo Rodríguez, "Preparation and Characterization of Ecuadorian Bamboo Fiber-Low-Density Polyethylene (LDPE) Biocomposites," *Evergreen Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **10** *(1)* 43-54 (2023). doi.org/10.5109/6781037
23) Kunal Singha, "A Short Review on Basalt Fiber," *International Journal of Textile*, **1** *(4)* 19-28 (2012). DOI: 10.5923/j.textile.20120104.02.
24) Indraneel R. Chowdhury, Richard Pemberton and John Summer scales, "Developments and Industrial Applications of Basalt Fibre Reinforced Composite Materials," *Journal of Composite Science*, **6** 367 (2022). https://doi.org/10.3390/jcs6120367.
25) Kaim Beng Yeo, Wei Jin Leow, Wai Heng Choong and Fadzilta Mohd Tamiri, "Hand Lay-up GFRP Composite Marine Propeller Blade," *Journal of Applied Science*, **14** *(22)* 3077-3082 (2014). DOI:10.3923/jas.2014.3077.3082.
26) S.Solomon Raj and Dr.P.Ravinder Reddy, "Performance evaluation of composite marine propeller using L8 orthogonal array," *International Journal of Engineering Science and Technology*, **3** *(11)* 7998-8003 (2011).
27) Gondi Konda Reddy and B. Sravanthhi, "Design and Analysis of a Propeller Blade Used for Marine Engine," *International Journal of Scientific Research in Science, Engineering and Technology*, **6** *(1)* 440-445 (2019). https://doi.org/10.32628/IJSRSET196179.
28) Muhammad Miqdad and Anne Zulfia Syahrial, "Effect of Nano Al_2O_3 Addition and T6 Heat Treatment on Characteristics of AA 7075 / Al_2O_3 Composite Fabricated by Squeeze Casting Method for Ballistic Application," *Evergreen Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **9** *(2)* 531-537 (2022). doi.org/10.5109/4794184.
29) Srirama Murthy Bellal, Kondapalli Siva Prasad and V. Murali Mohan, "Design and Manufacturing of Marine Propeller," *Trends in Machine Design*, **4** *(3)* 26-37 (2017).
30) H.J. Lin and J.F. Tsai, "Analysis of Underwater Free Vibrations of a Composite Propeller Blade," *Journal of Reinforced Plastics and Composites*, **27** 447-458 (2008). DOI: 10.1177/0731684407082539.
31) M. Bhanu Priya, K. Mohan Krishna and P. Giribabu, "Design and Analysis of a Propeller Blade," *International Research Journal of Engineering and Technology*, **2** *(6)* (2015).