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# Bio-inspired Design and Performance Evaluation of Lawnmower Cutter Blade

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## Abstract

*This study presents a bio-inspired design approach for the engineering applications of agricultural implements, with practical implications for the field. The CAD modeling of bio-inspired serrated lawnmower cutter blades was followed by structural and fatigue analysis with a comparative evaluation of the performance of conventional plain cutter blades. This method involved the bionic transformation of a biological model of the serrated leg of the grasshopper, traced using MATLAB edge detection and image processing software. The solid modeling CAD software for the Bionic Blade lawnmower cutter blade converts this biological model into an engineering model. After designing the geometric shape of the bionic tooth profile's serrated cutting edge, the boundary conditions are evaluated for numerical simulation based on the machine specifications of the conventional lawnmower cutter. After analyzing the power of the motor, the rotational speed, and the torque, the static structural and fatigue analysis was carried out in numerical simulation software to synthesize the performance of the bionic lawnmower cutter blade for engineering analysis of deformation, shear stress, and fatigue life. The bionic design of the blade and conventional plain blades were manufactured using an Amada CO2 laser cutting machine and sheet metal bending processes for Stainless Steel (SS 304) material. The experimental validation of software simulation was carried out by field trials using the Bionic design of a lawnmower cutter blade to evaluate the performance improvement in cutting time and yield of grass cut in kg for 60 to 100 meters distance cutting. After comparing the performance of the plain blade and the design of the bionic blade, there was a reduction in abrasive wear, a 12.87% improvement in the cutting time, and a 14.8% increase in the yield of grass compared to the conventional blade. This performance improvement was attributed to the unique bionic design of serrated cutting-edge and ground clearance. The bio-inspired design approach has immense practical applications in designing agricultural implements, as confirmed by this performance evaluation of this case study of bio-inspired lawnmower cutter blades.*

**Keywords:** *Bio-Inspired, Performance Analysis, Serrated Cutting Edge*

## 1.0 Introduction

Biomimetics is a research field gaining particular prominence due to various discoveries in biology and engineering. Structural bioengineering, including movement associated with biology, like the wings of birds, indicates that this research field significantly impacts scientific and technological disciplines.

From Leonardo Da Vinci's flying machines inspired by birds to the invention of Velcro, the knowledge captured in nature has resulted in very effective designs in various engineering applications. More recently, biological transformations in manufacturing have been combined with bio-inspired principle functions and structures to develop more sustainable manufacturing systems. With innovative ideas, bionic design relies on the

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analogical transfer of biological principles to engineering applications. Bio-inspired design applies knowledge of biological systems to research and development, solving technical problems and fostering innovation. It involves understanding natural functions, models, systems, and strategies and translating this knowledge into practical applications. Reel mowers and Rotary lawn mowers are used for mowing grass. Research has shown that rotary lawn mowers are more effective than reel mowers because they mow cleanly and have a provision for collecting grass.

The quality of cut, speed, angle, and sail of the cutting blade influence the mowing process. Rotary lawnmowers cut or mow grass, reducing the human effort needed to accomplish the task. They are more effective because they cleanly mow and have provisions for collecting grass. The most important part of the rotary mower is the cutting blade. The design, material, shape, and angle of the cutting blade are some of the most important factors influencing the quality of the cut.

Blade performance can be measured by factors or parameters like cutting efficiency, wear, torsional vibration, louder noise, friction, drag force, flow velocity, *etc*. To compare bionic and conventional lawnmower cutter blades, CAD modeling static structural and fatigue analysis was carried out using the bionic approach to compare the technical efficiency or improvement in blade performance. Willock *et al.* compared the recall performance of three different methods for identifying bio-i.nspired designs[1]. Wanieck *et al*. presented a study of existing tools that facilitate the process of biomimetics and the problems therein[2].

To obtain good holding and cutting capacities, they used a concave circle arc in the anterior end of the bionic blade and the radius of the concave. Production of a physical prototype using the Fortus FDM 400mc enabled faster and cheaper production of the artifact. Khodke *et al*., studied various developments and performances in grass cutter machines[3]. They considered using winglets to reduce the vortex effect in their design. Biologically inspired design integrates with tools and methods of other disciplines, such as project and innovation management. Chirazi *et al*., helped increase the understanding of the biologically inspired design process and assisted designers in overcoming challenges[4]. Hanan *et al*., presented the design and performance of TAUB, a jumping robot inspired by desert locusts[5]. The TAUB's jumping mechanism mimicked the legs of a desert locust for jumping. Shyam and Gopal[6] evaluated the fabrication and performance of mulch-type and flat-type blades in the field. For the mulch-type blades, the field efficiency of the grass cutter was 93.7%, and it could cut grass 20 mm above ground level with an average speed of 1.822 km/hr. For flat-type blades, the field efficiency of the grass cutter was 83.17%, and it could cut grass 20 mm high above ground level with an average speed of 1.89 km/hr.

Amer *et al.,* tested a rotary mower with five different blade cutting angles at five different cutting speeds to determine the pulverized percentage of sweet potato vine and the power consumed[7].

The best result was found for a 30° blade angle at 2440 rpm, with the highest rate of pulverized vine at 61.27%.

The 30° blade angle achieved the best performance at 1830 rpm, with the lowest power consumption of 44.00 joule. Jaison *et al.,* designed and analyzed cutting blades for rotary lawnmowers[8]. They used ANSYS FLUENT workbench software to perform static structural analysis and develop a new blade design. The blade was safe under various forces acting on it while rotating, and the design reduced the lawnmower's sound, preventing permanent health hazards. Versos and Coelho employed a design method for product development that does not create or guarantee success[9].

The FE analysis supported designers in selecting the most appropriate bionic design method. The researchers implemented several designs to prevent the grass from scattering away and increase the efficiency of grass transfer into the collecting bag. Mattheck *et al.,* used a method based on nature's design rules to remove underloaded parts in a mechanical component[10]. This was a graphic method of shape optimization that was demonstrated using examples.

Gokool *et al*., designed and developed a low-noise lawnmower blade[11]. Computer-aided design and computer-aided engineering tools and techniques were used to generate an optimized model of the original lawnmower blade prototyped utilizing a fused deposition modeling machine. Tong *et al*. investigated the working efficiency of the bionic blade, which was 12.5% higher than that of a conventional blade[12]. Using the digital image processing technique, the geometrical structure of the incisor of a bamboo weevil larva was studied, and its characteristic profiles were applied to the design of the bionic blades. Farzaneh studied the impact of bio-inspired design, transferring analogies from biology to develop novel technical solutions with innovation potential[13].

Individual participants performance in a single disciplinary pair and an engineer-biologist pair were analyzed. Yen *et al*., aimed to increase the understanding of the BID process and help designers overcome challenges[14]. The geometrical structure of the incisor of the bamboo weevil larva was studied using the digital image processing technique, and the characteristic profiles were applied to the design of the bionic blades. Besant and Richard developed a portable, durable, and easy-to-operate mower[15]. Nigral and Maria studied the jumping mechanism that mimics the legs of the locust with a mechanical tool inspired by nature[16]. An existing solution used in mountain bikes involves reinforcing the structure and incorporating mechanical suspension components to control and dampen oscillations. Warkins and Butler studied the design and manufacture of advanced lawnmowers[17]. The use of RP technology in fabricating the blade showed great potential in dropping developmental cost and time. Also, this technique reduced the number of personnel needed for a particular farm operation. Okafor *et al*., developed a domestic solar-powered lawn.mower of 0.13 m2/s field capacity for convenient operations[18]. The solar components were made with detailed design, and the test performance showed a field efficiency of 97%, demonstrating ease of use and a neat mowing process. The study by Zhao *et al*. explored the design and performance of a bionic cutting blade for corn stalks inspired by the unique mandibular structure of the ant[19]. Using stereoscopic microscopy and software tools like Origin and AutoCAD, the researchers analyzed the ant's mandible and identified the fourth maxillary tooth as the most effective for cutting. The bionic blade, modeled after this tooth, was compared to a conventional flat blade using finite element analysis and cutting tests.

The results showed that the bionic blade significantly reduced cutting force and energy consumption, making it more efficient for cutting corn stalks. The study concludes that the bionic blade offers superior mechanical properties and cutting performance, suggesting its potential for improving agricultural machinery. Nagpurkar *et al*., provide a detailed literature review on applying Finite Element Analysis (FEA) in engineering analysis, explicitly focusing on pressure vessels with catalyst bed reactors[20]. They emphasize optimizing design parameters to enhance pressure vessels' structural stability and stress distribution. This paper offers valuable insights for researchers and engineers looking to use FEA for efficient engineering analysis and design in various industrial settings. The most important part of the rotary mower is the cutting blade. The speed and angles of the blade influence the quality of the cut. A mower blade's improper shape and angle create torsional vibration and loud noise. Most lawnmowers have straight shafts and anti-vibration functions to reduce operator fatigue. Problems are caused by improper setting or mower blade adjustment, which damages the body and requires blade replacement. Material selection criteria are essential to avoid corrosion or rusting. Most mower blades are made of structural steel. Hence, frequent sharpening is necessary for good results. Sharpening is done by blade sharpener, grinder, file, *etc*.

After reviewing the literature and identifying the need for performance improvement to save electricity and reduce vibration and noise, the research objectives were the following: The first objective was to design an aerodynamic design. inspired by bird's wings, which would minimize turbulence, dust, and noise. The aim was to design a serrated-tooth bionic blade that reduces cutting resistance and abrasive wear by incorporating ground clearance[21]. This led to longer tool life and fewer frequent replacements or regrinds for lawnmower cutter blades. The outcome of this study was optimization in electricity consumption and ease of the farmer-gardener, leading to a reduction in the cost of the bionic blade lawnmower cutter.

## 2.0 Materials and Methods

The conventional material used for lawnmower cutter blades is structural steel. However, to impart good corrosion resistance, hardness, wear resistance, and toughness, stainless steel of SS 304 grade was selected for the design and subsequent manufacturing of serrated-edge bionic blades.

The material properties were as shown in Table 1.

**Table 1.** Material properties for conventional and bionic blade LMC

| Material | Density Kg/m$^3$ | Poisson's Ratio | Young's Modulus N/m$^2$ |
|---|---|---|---|
| Structural Steel | 7850 | 0.3 | 2x10$^{11}$ |
| SS304 | 8000 | 0.28 | 1.93x10$^{11}$ |

## 2.1 Modelling and Analysis Procedure

A lawn mower can easily cut a significant portion of farmland within a day, reducing human effort. In the current study, a bionic blade was designed, manufactured and experimentally tested to enhance the cutting speed and to reduce the wear of the lawn cutter blade.

To compare bionic and conventional lawnmower cutter blades, CAD modeling and Finite Element Analysis (FEM) was carried out, *viz*. static structural and fatigue analysis, to evaluate the improvement in deflection stresses and the fatigue factor. The field trials were conducted to evaluate the mowing efficiency and performance of the Bionic Blade lawnmower cutter blade. The Bionic blade serrated edge lawnmower cutter was compared to a conventional plain cutting edge in the field trials. The performance measures were the yield of grass cut per unit of time and the lawnmower's speed in the distance traveled per unit of time. Figure 1 shows an illustrative model of the development of bionic surfaces, which includes identifying some similarities in functional principles and initiating the process of biomimetic surface design.

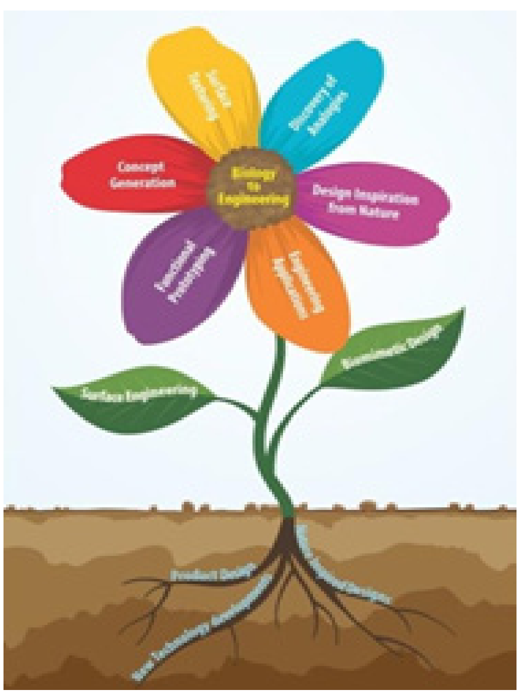


**Figure 1.** Illustrative model of development of bionic surfaces for engineering applications.

In the next step, nature-inspired design patterns, like a grasshopper's serrated leg, were traced by MATLAB edge detection image processing software and converted into geometrical two- dimensional drawings and CAD models for ANSYS software, as shown below.

### *2.1.1 Design Methodology Bionic Serrated Cutting-edge Lawnmower Cutters*

The following methodology was used to convert a biologically inspired design into a lawnmower cutter blade engineering model, as shown in Figure 2. First, a microscopic study was carried out by mounting the grasshopper's leg on an inverted metallurgical microscope and the serrated leg morphology was captured. In the second step, using MATLAB edge detection software, the trajectory of the leg of the grasshopper's zigzag thorny lag was traced.

In the third step, an AutoCAD drawing was created, followed by redesigning a CAD model using Solid Works software for the conventional and Bionic Blade Lawnmower cutter blade and engineering analysis of stainless steel 304 material. Modeling simulation and engineering analysis of the Bionic blade and the conventional blade were carried out for structural and fatigue analysis to evaluate deformation, stress, and fatigue factors, which helps analyze the performance of the Bionic blade against the conventional plain blade. The bionic Lawnmower cutter and conventional blades were manufactured using a CNC $CO_2$ laser cutting machine. This was followed by surface grinding and subsequent CNC bending to add ground clearance for a deeper cutting level and a reduction in friction and abrasion

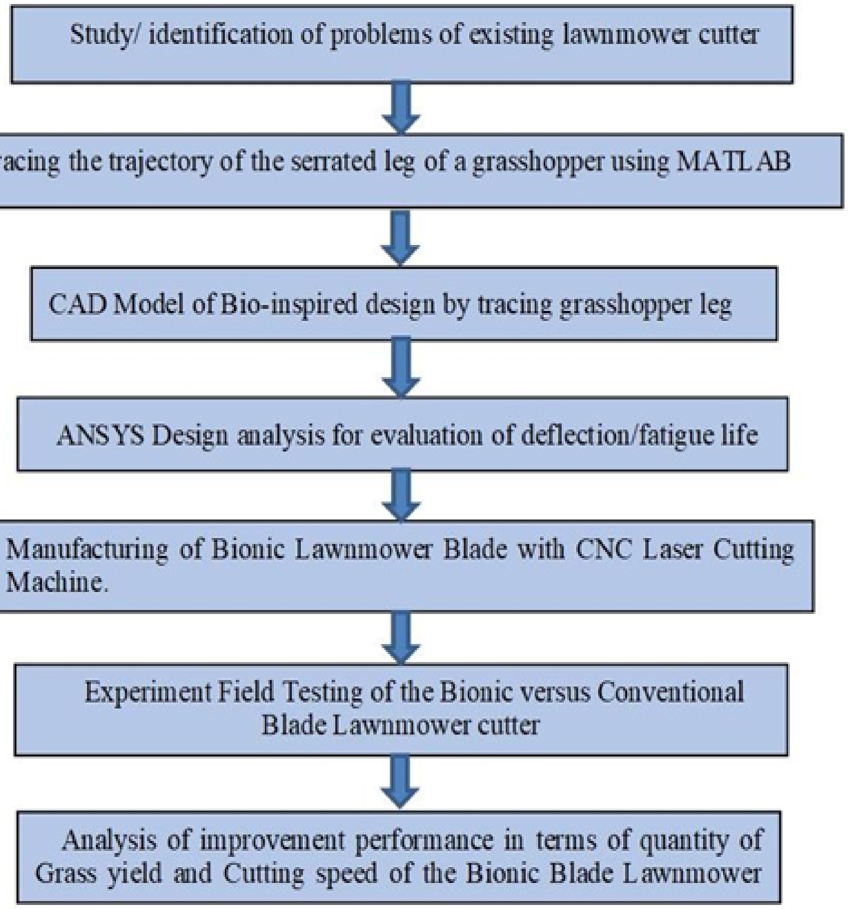


**Figure 2.** Design methodology of bioinspired blade lawnmower cutter.

with the ground. The experimental field trials validated the simulation findings.

A bionic blade Lawnmower cutter and a conventional blade were tested for actual performance for 60m, 70m, 80m, 90m, and 100m on the Falcon brand rotary-type cutter lawnmower. The specifications of the rotary-type lawnmower cutter were as follows. The make was FALCON, Model Roto Drive-33 Plus with Power 1400 watts, speed 3500 rpm, and weight 14.8 Kg. After analyzing the results of the field trials, it was observed that the time required to cut the grass for 60 to 100 m for a Bionic blade serrated edge lawnmower cutter blade was 15.15% less than that of the conventional blade. The grass yield for the Bionic blade was 17.03% more than that of the conventional blade.

### *2.1.2 CAD Modelling of Serrated Blade*

The bioinspired design of the lawnmower cutter blade was mimicked from the serrated leg of the grasshopper. Using MATLAB image detection software, the trajectory of the image captured of the grasshopper's leg as shown Figure 3 was transformed into the engineering design. The CAD Model using Solid Works 2021 software converted 2D model of the blade into a 3D SolidWorks model, as shown in Figure 3 of a lawnmower cutter blade. Figures 3(a) and 3(b) show the design synthesis of various versions of cuttertooth angles with 45 and 30-60-degree angles. The biological model of the grasshopper serrated leg Figure 3(c), engineered on a bionic blade lawnmower cutter model in Figures 3(d), 3(f), and 3(g), shows a plain blade with an example of a conventional sample specimen with structural steel material. Figure 3(f) shows the biological model of a serrated-leg grasshopper.

## 3.0 Results and Discussion

The following section describes the engineering design evaluation of structural and fatigue analysis of the bionic


**Figure 3.** Bioinspired lawnmower cutter blade (**a**) 45°-45°, (**b**) 30°-60° tooth angle (**c**) Bionic blade isometric. (**d**) Plain blade conventional € Plain blade rounded edge (**f**) Bionic blade (**g**) Grasshopper serrated leg.

lawnmower cutter against the plain blade cutter for 100 N radial force, as shown in Figure 4.

Effect of Various Cutting-edge Angles on the Structural and Fatigue Analysis of Bionic Blade Lawnmower Cutter

The static structural analysis was carried out on this blade design in ANSYS 2022 R1 software to analyze the static structural deformation of the blade with adaptive mesh refinement. The solver was mechanical APDL with structural steel and SS 304 material. Figures 4a to 4d illustrate the force distribution on different blade designs, including serrated configurations (45°- 45°, 30°- 60°, 60°- 30°) and a plain blade model. The blades show varying force concentrations along their cutting edges due to their unique geometries. In contrast, the plain blade presents a more uniform force distribution across the surface, indicating less complex interactions with the material. This suggests that serrated designs could enhance cutting performance by focusing forces on specific areas, potentially reducing overall resistance during operation.

Figure 5 depicts the total deformation experienced by each blade design under the same load conditions. The serrated blades exhibit slightly higher deformation values than the plain blade, with the 45°-45° serrated blade deforming by 0.12704 mm versus 0.01099 mm for the

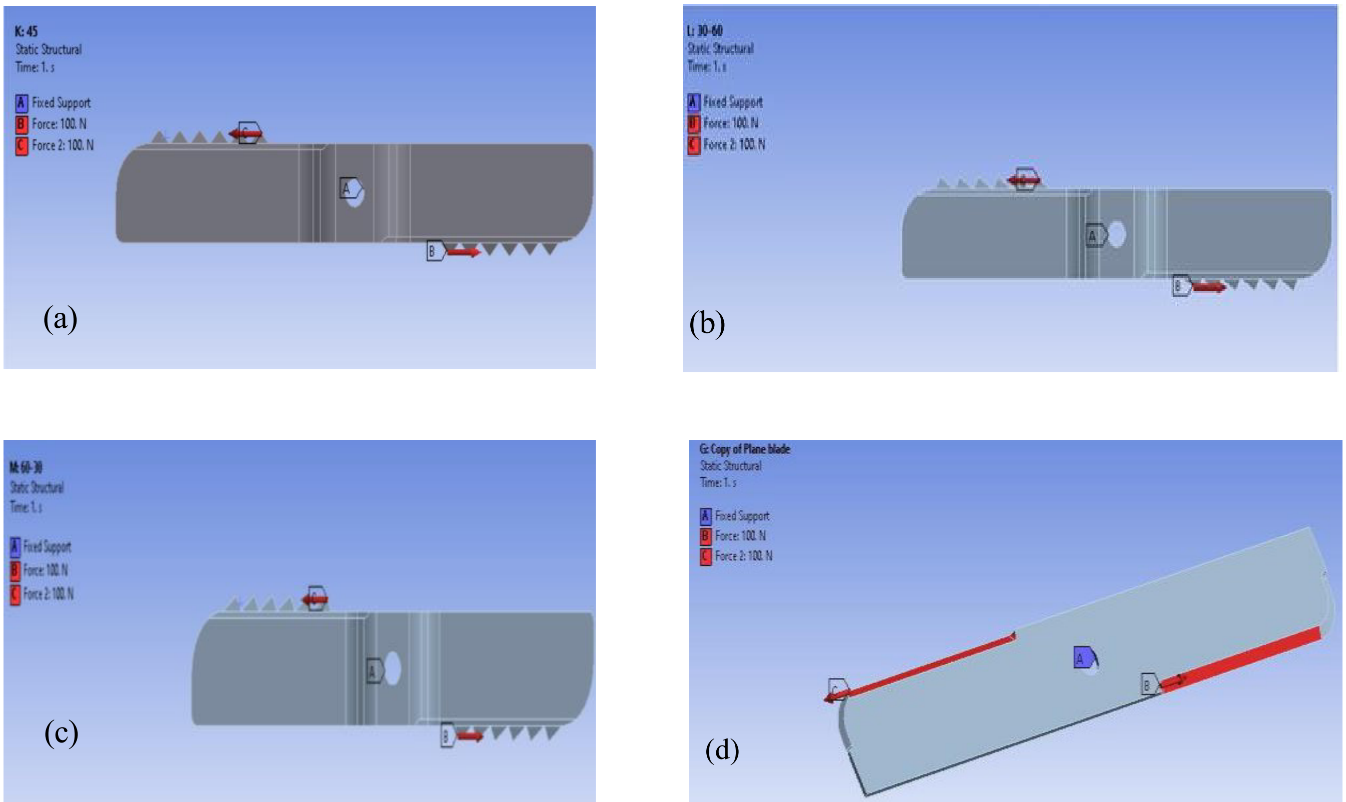


**Figure 4.** Static structural analysis (**a**) 45º-45º, (**b**) 30º-60º, (**c**) 60º-30º (**d**)Plain blade.

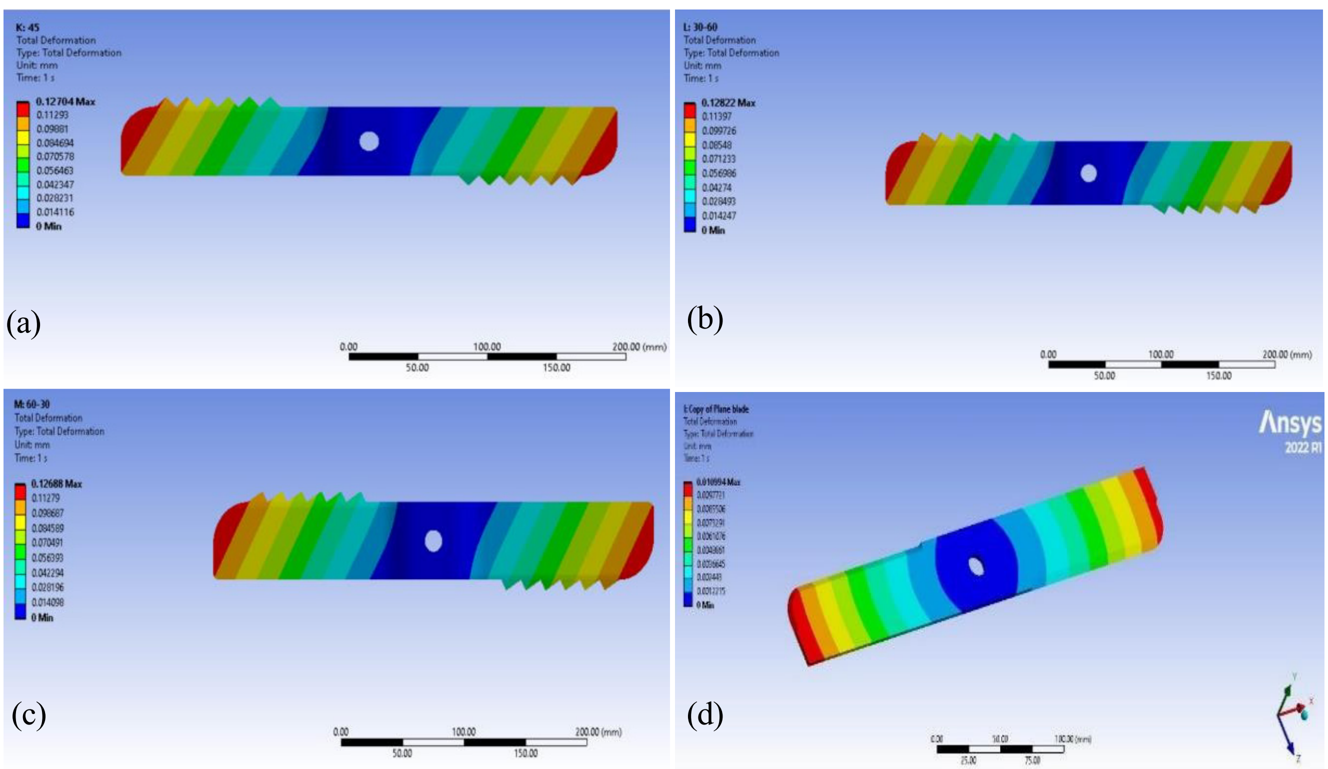


**Figure 5.** Total deformation due to applied load for (**a**) 45º-45º, (**b**) 30º -60º, (**c**) 60º -30º, (**d**) Plain blade model for static structural analysis.

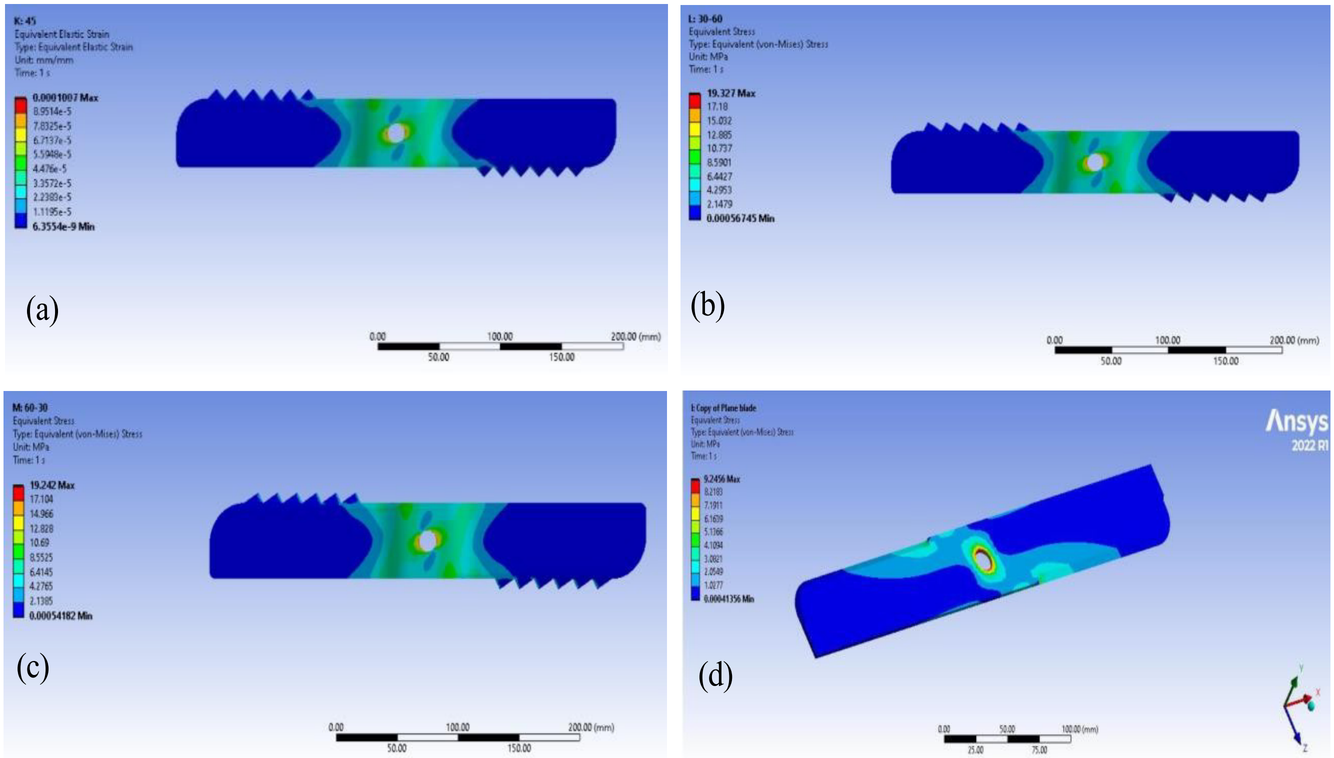


**Figure 6.** Equivalent stress distribution due to applied load for **(a)** 45°-45°, **(b)** 30° -60°, **(c)** 60° -30°, **(d)** Plain blade model for static structural analysis.

plain blade. This increase in deformation indicates that the serrated designs allow for more flexibility, which may help absorb impact and reduce the risk of blade fracture. However, the deformation remains within acceptable limits, ensuring these blades can handle operational loads without compromising performance.

Figure 6 shows the equivalent stress distribution for each blade design. The serrated blades demonstrate significantly higher stress levels than the plain blade, with the 45°-45° serrated blade reaching an equivalent stress of 19.177 MPa compared to 9.2456 MPa for the plain blade.

This higher stress concentration without a red spot at the central pivot, as seen in Figure 6d for the plain blade, indicates that the serrated design enables the blade to endure greater forces, enhancing its cutting efficiency. Despite this, the material's strength ensures that the stress levels are within safe limits, highlighting the effectiveness of serrated blades in high-stress environments.

Figure 7 shows the fatigue analysis for the 45°-45° serrated blade. The study indicates that this blade design

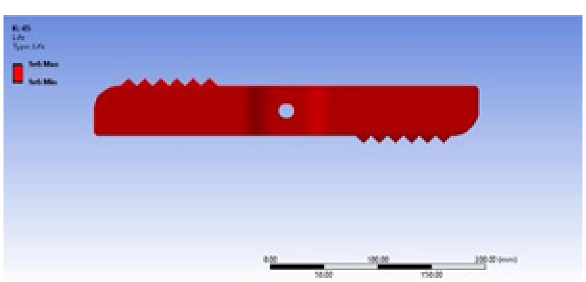

**Figure 7.** Fatigue analysis of 45°-45° blade.

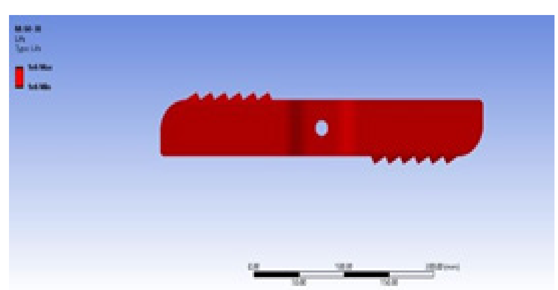

**Figure 8.** Fatigue analysis of 60°-30° blade.

can withstand cyclic loading with a fatigue life of around $10^6$ cycles. This high fatigue life demonstrates the blade's ability to endure repeated stress without significant degradation. The serrated design effectively disperses stress across the blade, reducing the risk of fatigue failure. The blade's geometry and material properties contribute to its durability, making it suitable for long-term applications.

Figure 8 presents the fatigue analysis for the 60°-30° serrated blade. Similar to the 45°-45° blade, this design shows a fatigue life of 10^6 cycles, indicating robust performance under cyclic loading. The variation in serration angles helps manage stress distribution differently from other designs.

The 60°-30° configuration provides a unique balance between cutting efficiency and durability. It demonstrates that altering the serration angles can influence the blade's resistance to fatigue, potentially optimizing performance for specific applications. Figure 9 depicts the fatigue analysis for the .30°-60° serrated blade. This blade design also exhibits a high fatigue life of $10^6$ cycles, similar to the other serrated designs. The staggered angle pattern of the serrations contribute to its ability to handle repeated stress effectively.

This design offers a different stress distribution pattern compared to the 45°-45° and 60°-30° blades. It shows that the 30°-60° configuration can also maintain structural integrity over prolonged use, demonstrating the versatility of serrated designs in enhancing fatigue resistance.

Figure 10 shows the fatigue analysis for the plain blade. In contrast to the serrated designs, the plain blade has a lower fatigue life of 10^5 cycles. This indicates that it is more susceptible to fatigue failure under cyclic loading. The lack of serrations means that stress is less effectively distributed across the blade, leading to a higher likelihood of micro-crack formation and propagation. Consequently, while the plain blade may perform adequately, it is less durable over time than its serrated counterparts. In this way, Table 2 clearly shows that altering the blade angle does not influence the deformation and stresses experienced by the material under the specified boundary conditions.

**Table 2.** Performance evaluation of various cutting-edge angles for bionic blade LMC

| Blade Angle (°) | Force (N) | Material | Deformation (mm) | Equivalent Stress (MPa) | Shear Stress (MPa) | Elastic Strain | FoS | Fatigue (Cycles) |
|---|---|---|---|---|---|---|---|---|
| 45. | 100 | SS304 | 0.12704 | 19.177 | 7.107 | 0.000100 | 10.69 | $10^6$ |
| 30-60 | 100 | SS304 | 0.12822 | 19.327 | 7.04 | 0.000101 | 10.607 | $10^6$ |
| 60-30 | 100 | SS304 | 0.12688 | 19.242 | 7.12 | 0.000101 | 10.654 | $10^6$ |
| Plain blade | 100 | SS304 | 0.01099 | 9.2456 | 0.475 | 0.000006 | 15 | $10^5$ |

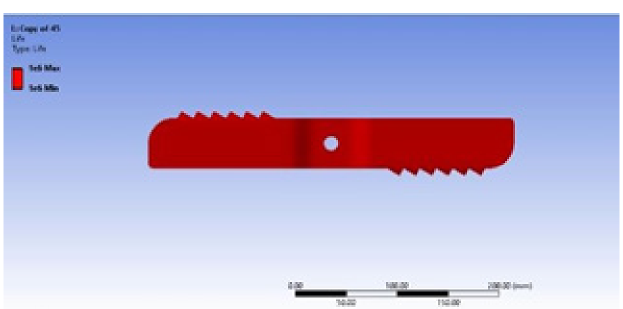

**Figure 9.** Fatigue analysis of 30°-60° Blade.

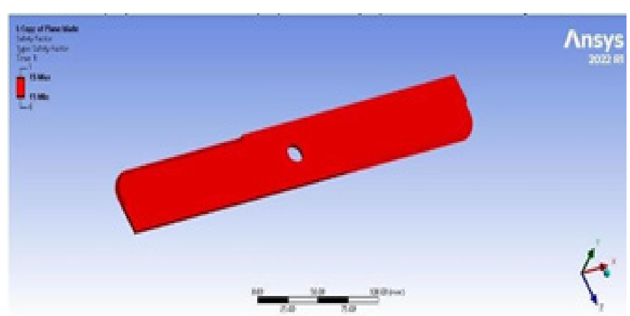


**Figure 10.** Fatigue analysis of plain blade.

## 3.2 Effect of Change in Material for ANSYS Structural and Fatigue Life Evaluation

This section depicts the effect of a change in material, *viz.*, structural steel and stainless-steel SS 304, on the output for structural and fatigue evaluation for plain and bionic blades.

Figure 11 illustrates the force constraints applied to different blade designs: The plain blade, the bionic blade with structural steel, and the bionic blade with 304L SS.

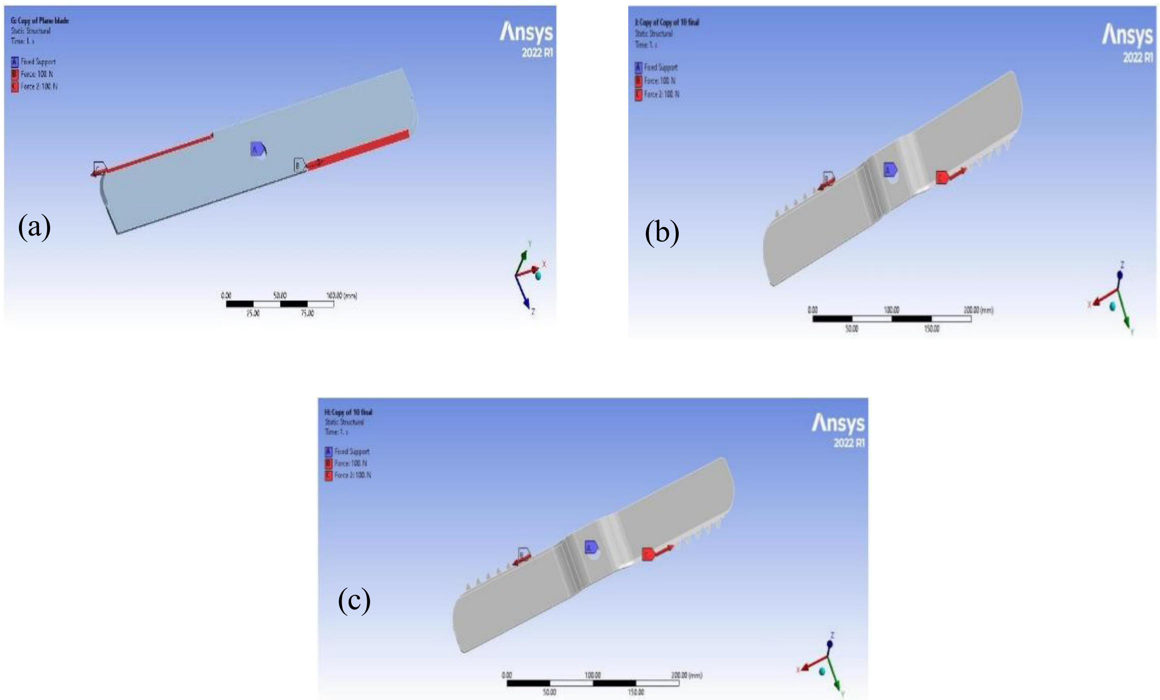


**Figure 11.** Force constraints **(a)** Plain blade, **(b)** Structural Steel, **(c)** 304LSS.

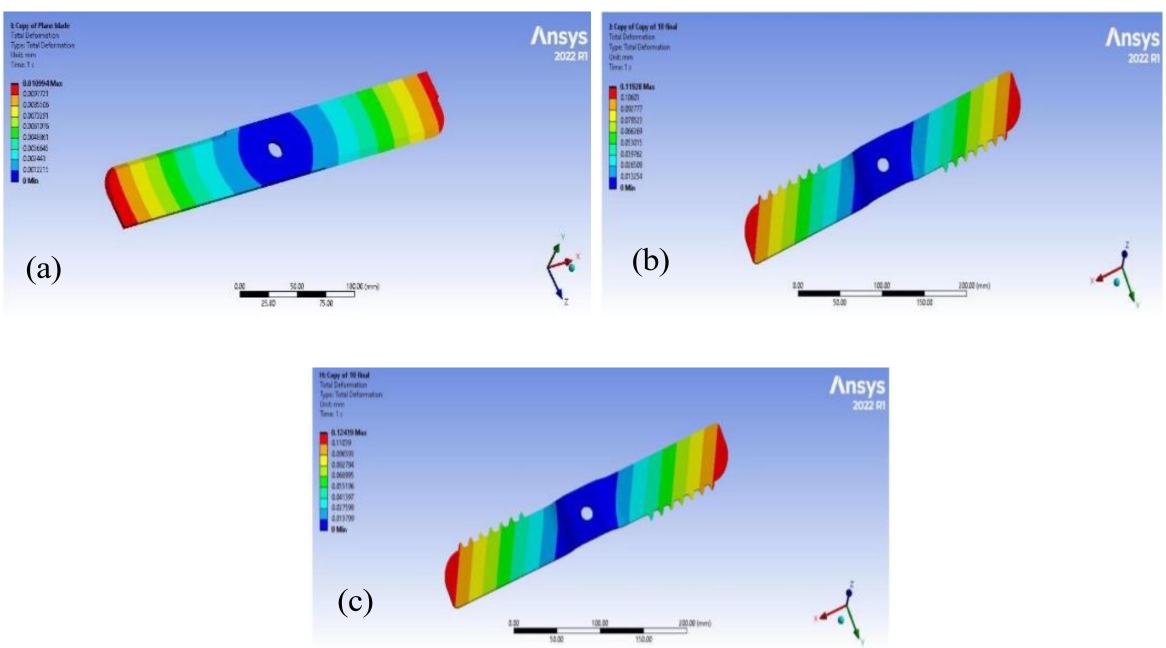


**Figure 12.** Total deformation **(a)** Plain blade, **(b)** Structural Steel **(c)**304L SS.

The analysis shows that the force distribution is more uniform in the plain blade, while the bionic blades exhibit variations in force concentration due to their serrated edges. This indicates that the bionic blades can handle higher force constraints, enhancing their cutting efficiency. The force distribution in the bionic designs suggests an improved interaction with the material being cut, leading to potentially more effective performance.

Figure 12 depicts the total deformation experienced by the blades under static loading conditions. The plain blade shows minimal deformation, measured in the range of micrometers, while the bionic blades, particularly those made of 304L SS, exhibit higher deformation values. This suggests that the bionic blades, despite being more flexible, can endure operational loads effectively without compromising their structural integrity. The increased deformation in bionic blades could allow for better energy absorption during cutting, reducing the likelihood of fractures and enhancing the blade's adaptability to varying cutting conditions.

Figure 13 shows the equivalent stress distribution in the plain blade, structural steel bionic blade, and 304L SS bionic blade. The plain blade experiences significantly lower stress levels, whereas the bionic blades show much higher equivalent stresses, with the 304L SS blade reaching up to

19.12 MPa. This indicates that the bionic blades are designed to handle more demanding conditions, making them more suitable for high-performance applications. The higher stress in bionic blades also suggests they can deliver greater cutting forces, contributing to more efficient material removal.

Figure 14 (a-c) illustrates the shear elastic strain in the plain and bionic blades. The bionic blades exhibit higher strain values compared to the plain blade, indicating their ability to undergo more elastic deformation before reaching their yield point. This characteristic is crucial for handling dynamic loads during cutting, as it allows the bionic blades to flex and adapt without sustaining permanent deformation. The enhanced elastic strain in bionic designs contributes to their overall resilience, making them less prone to damage under varying operational stresses.

Figure 15 presents the shear stress distribution for the plain and bionic blades. The plain blade shows minimal shear stress, while the bionic blades, especially the 304L SS blade, exhibit significantly higher shear stresses. This indicates that the serrated designs are more

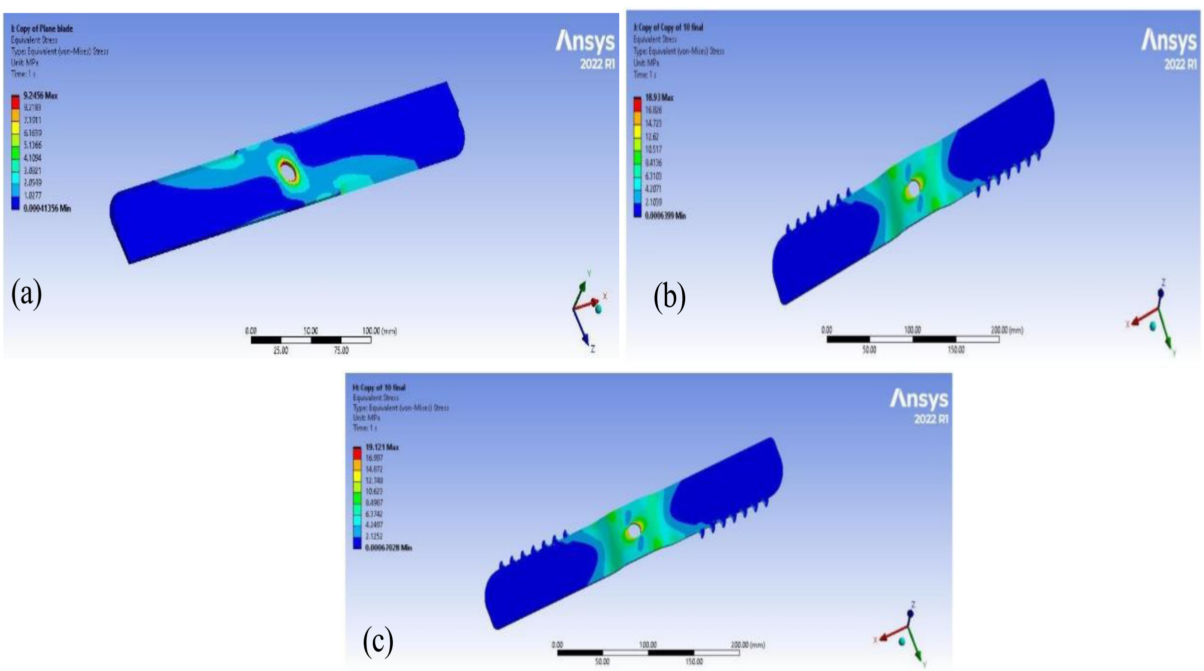


**Figure 13.** Equivalent stress **(a)** Plain blade, **(b)** Structural steel, **(c)** 304L SS.

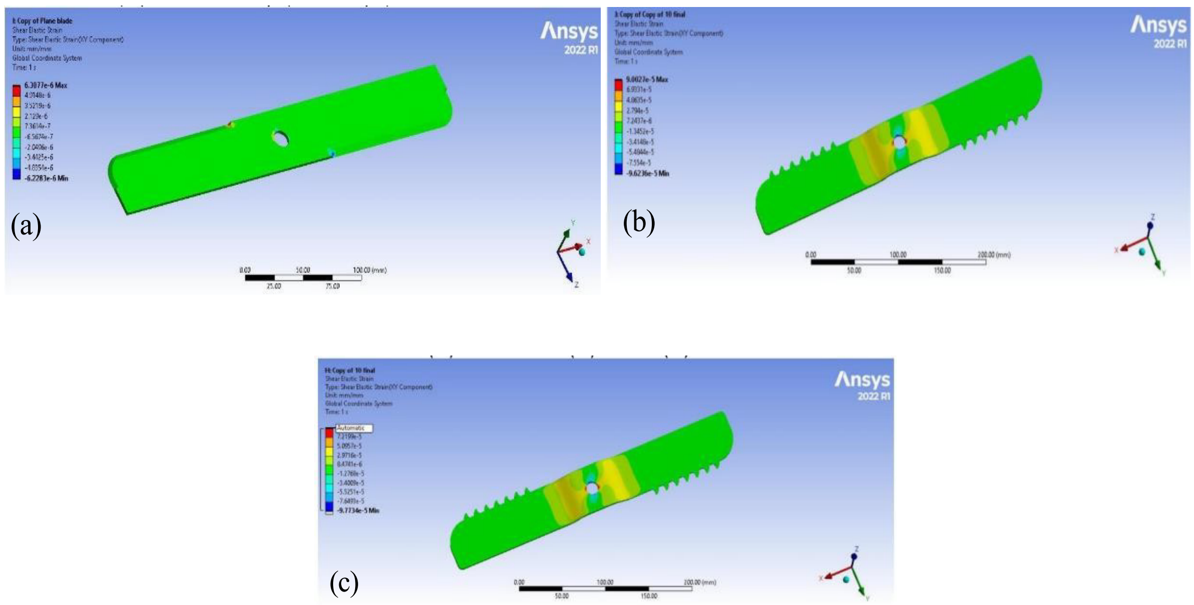


**Figure 14.** Shear elastic strain **(a)** Plain blade, **(b)** Structural steel, **(c)** 304L SS.

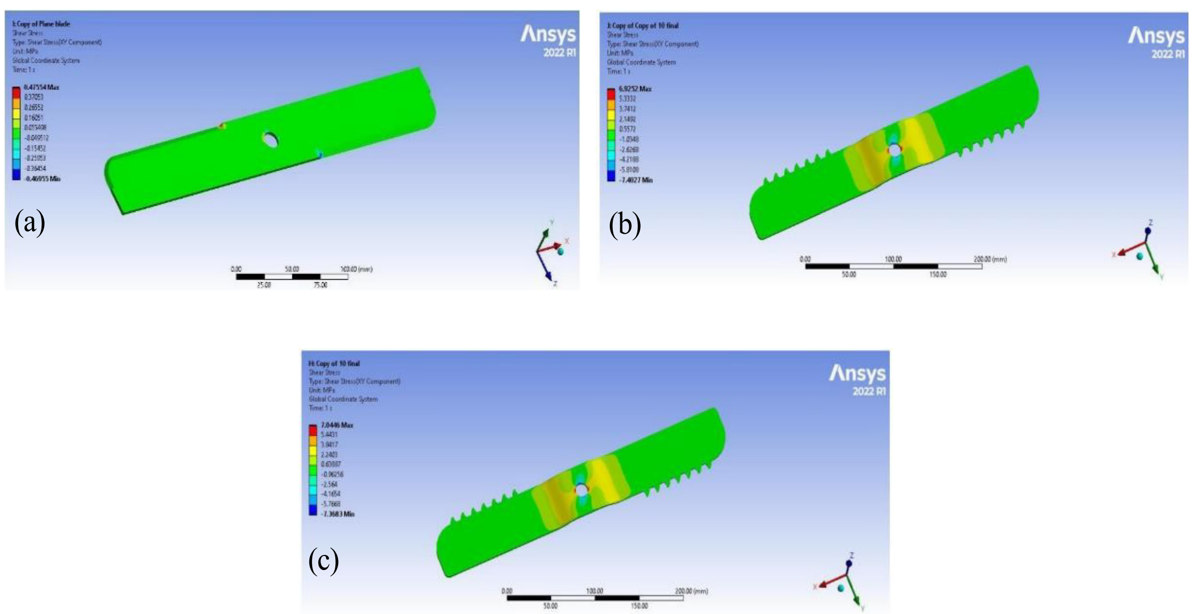


**Figure 15.** Shear stress **(a)** Plain blade, **(b)** Structural steel, **(c)** 304L SS.

effective in handling shear forces, which are critical during cutting. The increased shear stress capacity of bionic blades enhances their ability to cut through rigid materials with reduced risk of failure, improving their overall performance and longevity in practical applications. This study compares the bionic and plain blades regarding mechanical and structural performance based on simulation data from ANSYS and experimental observations. The critical parameters assessed include static deformation, stress distribution, and fatigue life.

Table 3 shows that the plain blade demonstrates minimal deformation of $4.2755 \times 10^{-6}$ mm under

**Table 3.** ANSYS simulation results for structural analysis

| Parameter | Plain Blade | Bionic Blade- Structural Steel | Bionic Blade- 304L SS |
|---|---|---|---|
| Static Deformation (mm) | $4.2755\times10^{-6}$ | 0.11928 | 0.1249 |
| Normal Stress (MPa) | 0.002111 | 18.93 | 19.12 |
| Shear Stress (MPa) | 0.000116 | 6.9252 | 7.044 |
| Principal Elastic Strain | $1.2538\times10^{-8}$ | $9.0027\times10^{-8}$ | $9.344\times10^{-8}$ |

maximum total static load. In contrast, the bionic blades, constructed from 304L stainless steel and structural steel, exhibit higher deformation values of 0.1249 mm and 0.11928 mm, respectively. Despite these higher values, the bionic blade's deformation levels remain within acceptable limits, suggesting that its structure enhances flexibility and can handle operational loads effectively without compromising performance. This increased flexibility could result in greater resilience under real-world operational conditions.

### 3.2.2 *ANSYS Simulation Results for Fatigue Analysis*

Figures 16 a, b, and c provide the fatigue analysis for the plain blade, bionic blade made of structural steel, and bionic blade made of 304L SS, respectively. The blade demonstrates a fatigue life of $10^5$ cycles, similar to the plain blade in numerical value, but with a more effective stress distribution pattern. The bionic design helps reduce localized stress concentrations, mitigating the crack

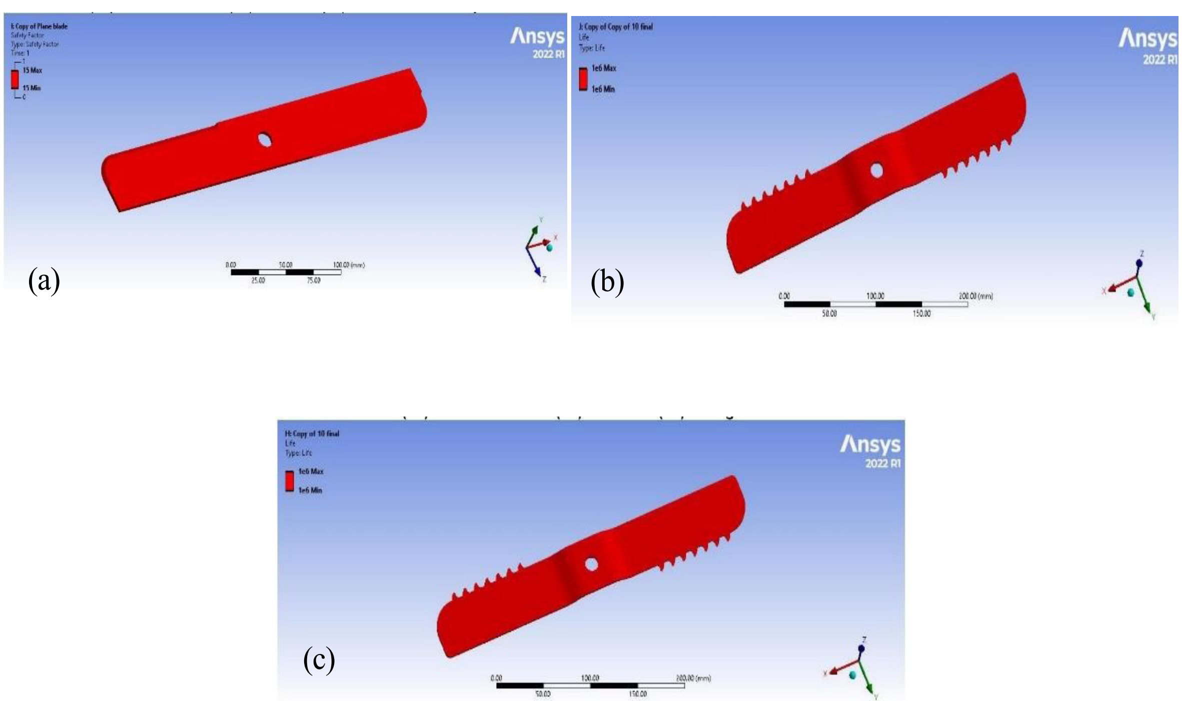


**Figure 16.** Fatigue analysis **(a)** Plain blade **(b)** Bionic structural steel **(c)** Bionic 304L Stainless Steel

**Table 4.** ANSYS Simulation results for fatigue analysis

| Par.ameter | Plain Blade | Bionic Blade- Structural Steel | Bionic Blade- 304L SS |
|---|---|---|---|
| Safety Factor | >10 | >10 | >10 |
| Fatigue Life (Cycles) | $10^5$ | $10^5$ | $10^5$ |

initiation and propagation risk. The structural steel bionic blade's enhanced fatigue resistance can be attributed to its serrated geometry, which aids in distributing loads more evenly across the blade surface, extending its durability.

As shown in Table 4, both blades have a fatigue life rating of $10^5$ cycles in simulations. However, the bionic blade demonstrates superior stress distribution and material strain management performance, indicating that it may have a longer operational life in practical applications. The bionic blade's aerodynamic profile and material handling capabilities reduce the likelihood of micro-crack propagation, which is crucial for extending the lifespan of components subjected to repetitive loading cycles.

Furthermore, both blade designs have safety factors more significant than 10, indicating that they operate within safe stress limits. While the plain blade is adequate in terms of safety, the bionic blade's additional benefits, such as better deformation control and stress distribution, highlight its superior structural integrity over extended periods of use.

## 3.3 Field Trials for Bionic and Plain Cutting-edge Lawnmowers for Evaluation of Cutting Performance

The results obtained from the static structural analysis and fatigue analysis revealed that SS 304 and structural steel blades were within the permissible limit for the given

(a)

(b)

(c) (d)

**Figure 17.** **(a)** Plain edge cutting **(b)** Bionic $CO_2$ laser serrations cutting. **(c)** Surface Grinding Process **(d)** CNC Bending Process

loads and the boundary conditions. Hence, the concept of using SS 304 material was carried forward to evaluate the field performance of the bionic blade versus the conventional plain blade, as shown in Figure 19.

The blades are manufactured and tested in the field for mowing grass.

#### 3.3.1 *Fabrication of Bionic Lawn Mower Blade Using CNC Laser Cutting Machine*

As shown in Figure 17, the fabrication of the blade was initiated from a material selection like SS 304 and importing the AutoCAD drawing of the plain and bionic blade. An AMADA laser CNC machine, as shown in Figure 17(a), was used to cut the bioinspired design of the blade, and the CAD model was required to process the design. The bionic blade serrated edge cutting edge was manufactured after importing the CAD design into the $CO_2$ Laser cutting CNC machine. A drilling machine was used to drill the centre hole for the lawnmower blade with the help of the 7 mm drill bit. After drilling the central hole, the tool grinding machine was used to sharpen the bionic lawnmower's edge, as shown in Figure 17(c). An angle grinder was used to get a specific angle edge. The design incorporated a curve bending to increase


**Figure 18.** **(a)** Field testing of bionic blade Lawnmower Cutter **(b)** Plain blade *vs* Bionic blade (SS 304) Lawnmower cutter

the ground clearance, significantly improving the blade's performance. The bending process was done on the CNC bending machine, as shown in. Figure 17(d).

This process increased the blade's ground clearance. After the process's bending, the final hand grinding was required to be finished. This was done with sand grinding paper. The sand-grinding paper smoothed the blade's unwanted sharp edges, making it easy to handle.

### *3.3.2 Field testing of Bionic blade Lawn Mower Cutter*

The following section deals with the procedure for testing the lawnmower cutter blades in the field for cutting grass, as shown in Figure 18. As there was less surface-to-surface contact for the bionic blade, the abrasion and adhesive wear were found to be less for the bionic blade due to the ground clearance provided in the modified design. This also resulted in lesser adhesion of the muddy soil or grass cut to the blade's surface, reducing drag force and friction.

### *3.3.3 Efficiency in Cutting Time*

Figures 19 and 20 show that the bionic blade consistently performed better than the plain blade in reducing cutting time at different distances. On average, the bionic blade improved cutting time by 12.87%. The highest reduction of 15.15% was observed at an 80-meter distance. This improvement is attributed to the optimized blade

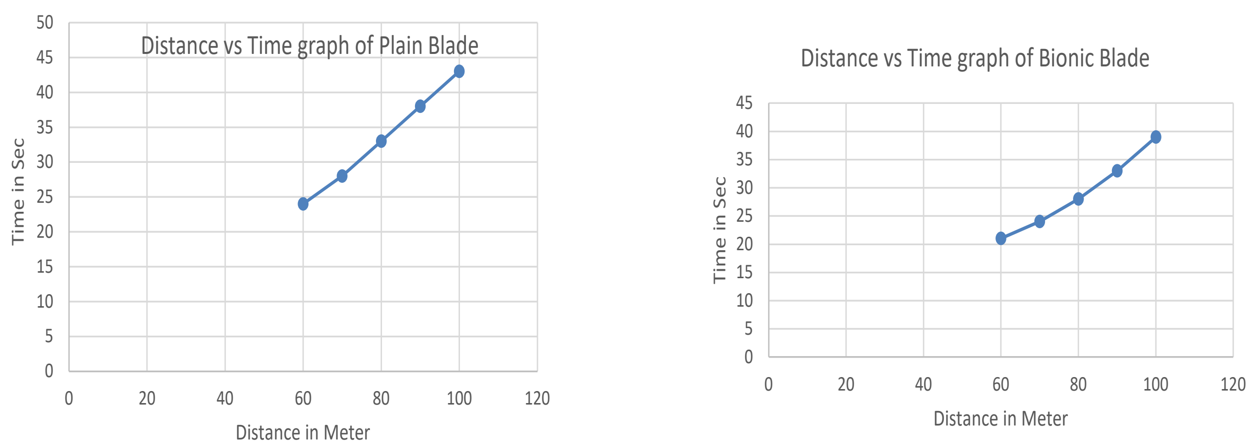


**Figure 19.** Distance vs time for plain and bionic blade.

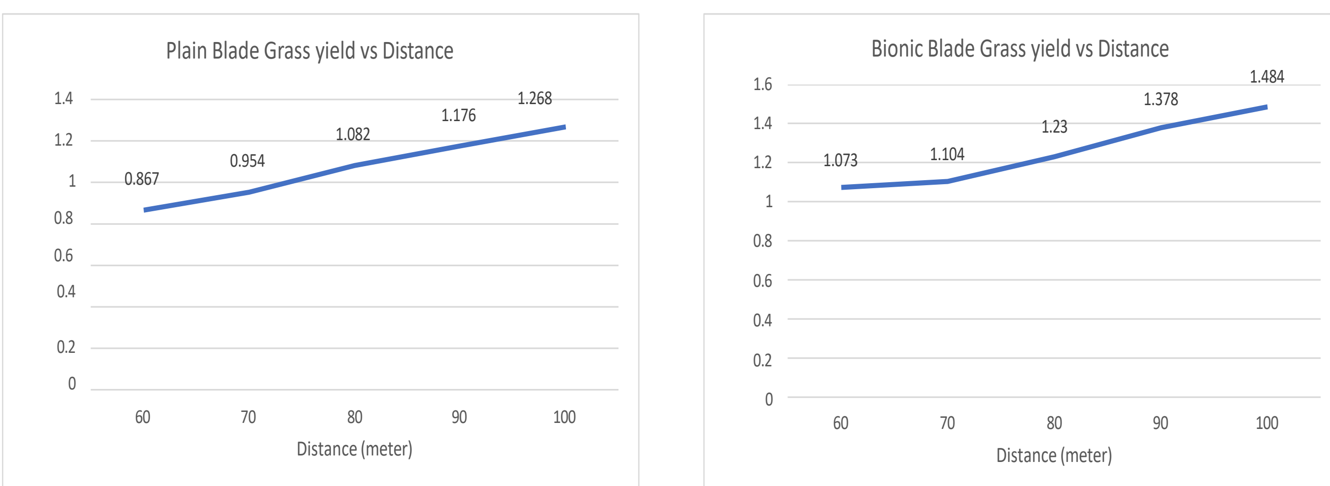


**Figure 20.** Grass yield(kg) vs Distance (m) for Plain and Bionic blade

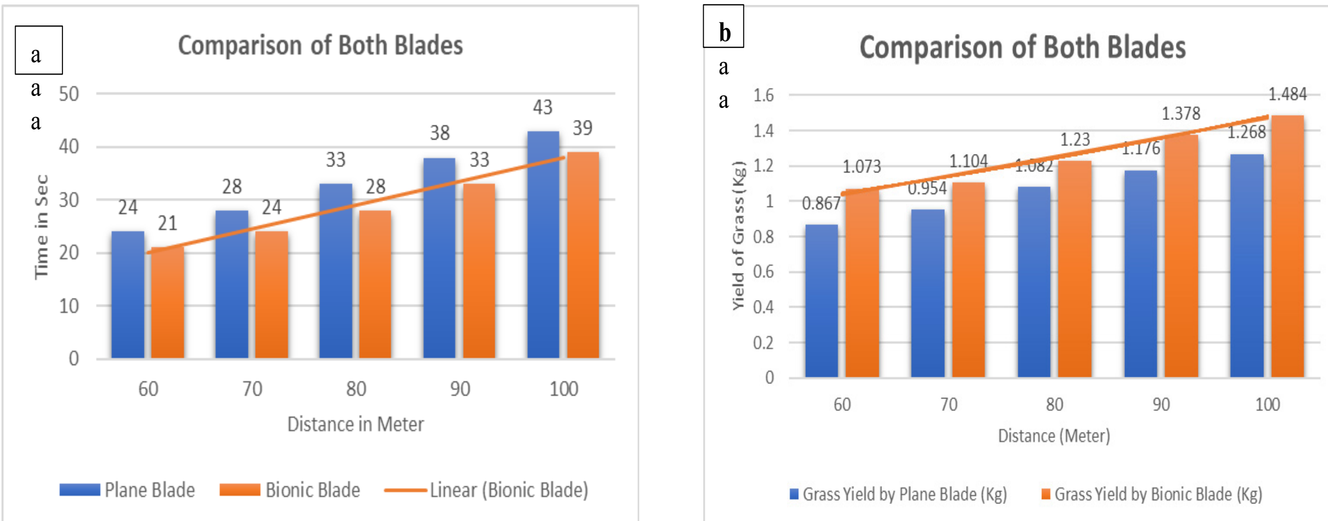


**Figure 21.** Field trial comparison for Plain vs Bionic blade.

geometry and cutting-edge design, which allow for more efficient grass-cutting with reduced resistance.

### *3.3.4 Improvement in Grass Yield*

According to Figure 20 the bionic blade also significantly increased grass yield across all distances, with an average increase of 14.80%. The highest yield improvement was recorded at a .60-meter distance, showing a 19.19% increase in grass collected.

As shown in Figure 21, the higher yield efficiency is likely due to the bionic blade's ability to maintain sharper edges and enhance cutting precision, resulting in more effective grass collection.

In this way, even though in the ANSYS Simulation, the structural deformation, stress, and fatigue life were not very significant in bionic and conventional blade lawnmower cutters, the field trials showed a significant impact on the lawnmower's performance in terms of cutting speed and the yield of grass in each pass from 60 meters to 100-meter distance trial. The implementation in performance was also analyzed for wear and service life in hours.

The parameters of improvement were a 12.87% reduction in cutting time, a 14.8% improvement in the yield of grass in Kg per pass from 60 to 100m, a decrease in power consumption, energy savings, and cost reduction, which impacts the environment and sustainability. The bioinspired blade design enhances both mechanical performance and cutting efficiency. The blade's structure reduces deformation and stress, contributing to its superior durability and operational lifespan. The blade's 30° cutting angle is critical in optimizing cutting action, reducing drag, and enhancing overall performance in field conditions.

In practical terms, using the bionic blade can reduce mowing time and increase grass yield, making it a highly efficient alternative for residential and commercial lawnmower applications. The improved fatigue life and cutting efficiency indicate that the bionic blade can withstand extended use with minimal wear, reducing maintenance costs and operational downtime.

## 4.0 Conclusions

1. The bionic lawnmower blade, inspired by nature, showed significant performance improvements compared to traditional blades, with a 12.87% reduction in cutting time and a 14.80% increase .in grass yield across different distances.
2. Made from SS304 and structural steel, the bionic blades demonstrated enhanced flexibility and resilience under operational loads. Bionic blades exhibited superior shear and average stress resistance compared to plain blades, increasing durability and operational longevity.

3. Both plain and bionic blades had a fatigue life rating of $10^5$ cycles. Still, the bionic blade's design allowed for better stress distribution and material strain management, indicating a potentially longer operational life. The safety factor for both blades exceeded 10, ensuring safe design limits for fatigue life.
4. The bionic blade's aerodynamic and serrated design reduced cutting resistance, wear, and drag, resulting in less power consumption and longer tool life. This showcases the potential of bio-inspired designs for efficiency and sustainability in mechanical engineering applications.
5. The ground clearance in the bionic blade reduced the contact area with soil and abrasive wear or adhesion of grass cut to the blade surface. This prolonged the service life of the lawnmower cutter and reduced frequent replacements due to reduced wear and improved cutting efficiency. The outcome of this new design was reduced electricity consumption, offering sustainable solutions by fostering environmental protection.

## 5.0 Future Scope.

An attempt was made to carry out a Finite element analysis using ANSYS to study the effect of variation in cutting edge tool angles like 45º-45º or 30º -60º on structural and fatigue analysis. However, the improvement in field performance to cut various types of grass due to the change in tool angle leading to subsequent improvement in impact strength due to an alternative material, stainless steel SS 304, would be the objectives of the future scope of this study.

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