Environmental and Climate Technologies
2025, vol. 29, no. 1, pp. 471–482
https://doi.org/10.2478/rtuect-2025-0032
https://content.sciendo.com

Design and Optimization of a Welded Structure for a Mobile Power Station with Complex Configuration

Armand PELLJA[1*], Olga LIIVAPUU[2], Jüri OLT[3]

[1–3]*Estonian University of Life Sciences, Fr. R. Kreutzwaldi 56, Tartu, Estonia*

Received 20.03.2025; accepted 12.05.2025

Abstract **– Energy storage and its utilization, regardless of location, enable the provision of critical services and machinery operation in remote and isolated areas, such as rural regions, islands, or in war and crisis scenarios. By employing modern energy production and storage systems, it becomes possible to ensure a reliable energy supply in areas with inadequate or damaged electrical infrastructure. During the design of the mobile energy solution, a critical objective is to minimize the overall weight of the structure. For this purpose, the primary construction material is the lightweight yet durable heat treated and artificially aged aluminum alloy profiles, which forms the structural framework for both the station and the solar panel mounting and moving system. Structural integrity is as strong as the weld and base material connecting the profiles. Constructing renewable energy station from superior lightweight materials offers significant energy and sustainability benefits such as reduced material usage, fuel efficiency, and carbon emissions. The research findings highlight the importance of understanding the metallurgy of heat-treated aluminum alloys, particularly after welding, to ensure the structural integrity of constructions made from aluminum alloy 6082T6. When heat-treated aluminum alloys are subjected to welding, the material's mechanical parameters can weaken due to changes in its microstructure. Using a reverse engineering approach, input data from destructive testing results were analyzed to better understand these material mechanical parameters. The case study of a mobile power station illustrates how this knowledge is applied in practice, emphasizing the need for metallurgical insights to maintain the performance of mobile power station construction. The study concludes that tailored welding processes are crucial to minimizing the adverse effects of heat input on the material properties of heat-treated aluminum alloys. Lowering the heat energy input for structural manufacturing is energy saved from manufacturing. Considering these effects, manufacturers can leverage the alloys mechanical advantages in lightweight constructions, thus expanding their applicability in industries focused on weight reduction and structural integrity. These findings provide valuable insights into advancing innovative engineering solutions in sectors such as transportation of renewable energy stations, aerospace, and marine. Overall selecting a proper manufacturing technology, materials and methods results in energy efficiency and allow for innovative structural solutions for welded structures with a complex configuration.**

Keywords **– Energy production; mobile renewable power station; solar power; structure welding; structural integrity.**

* Corresponding author.
E-mail address: armand.pellja@emu.ee

1. INTRODUCTION

Energy access remains a critical challenge in remote and isolated areas, during emergencies or outdoor activities [1], where grid electricity is often limited or unavailable. This challenge is further amplified by rapid global population growth, which demands both agricultural intensification and reliable off-grid energy solutions. The agricultural sector is increasingly adopting autonomous robotic systems to meet growing production needs. These systems require continuous, reliable power in field conditions where traditional infrastructure is absent.

A rapid increase in population leads to increase in power generation. The increase in power generation emits pollution which is dangerous for environment [2]. Renewable energy sources provide cheap and clean energy to compare to non-renewable energy sources [3]. The development of autonomous agricultural robots has further highlighted the need for efficient energy solutions. These robots require continuous operation in remote, off-grid areas. In order to fulfil robot's energy needs in various locations: energy can be generated on site using mobile power station, see Fig. 1. In order to design the appropriate mobile solar power station, it is essential to first understand the specific energy requirements. The design process must consider factors such as average daily solar energy input, daily load demand, and the sizing of the solar station energy harvesting components [4]. This study investigated the adaptability of mobile charging station to diverse energy requirements, considering factors such as location, load type, and variability in demand [5]. Hybrid energy generation systems are widely used to increase energy output and ensure reliability [6]. Stations combine multiple energy sources, like solar, wind, hydrogen, compressed natural gas (CNG) to meet varying energy demands, providing a sustainable and efficient energy solution.

The current mobile solar power station is specifically designed to meet the energy demands of an agricultural robot such as for automated berry cultivation [7]. As outlined in the article [8], the station's output power has been calculated to ensure a continuous and reliable energy supply, enabling the robot to operate autonomously in the field without the need for operator intervention.

The station powers the agricultural robot and supports its continuous operation through integrated systems. Energy is harvested from sunlight, converted, and stored in a changeable battery pack. Additionally, the station includes a fertilizer tank equipped with an automatic refilling mechanism and alternative energy source for power generation reliability. These features ensure the robot can operate efficiently on the field.

A distinctive feature of the station is its solar tracking system The solar tracking system optimized energy capture, see [9] for efficiency comparison, ensuring optimal energy capture throughout the day. All sides of the frame are covered with solar panels to maximize energy generation, making the station highly efficient and self-sufficient. The mobile solar power station provides a reliable energy source, eliminating the need for external power and ensuring continuous operation for agricultural robots. The station forms a closed environment, allowing for the safe transportation of the agricultural robot and ensuring its readiness for uninterrupted field operations. Mobile power station field working configuration is shown in Fig. 1. To meet the requirements of the agricultural robot, the station's structure must be constructed from a lightweight yet high-strength material. By using lightweight yet high-strength metal for the solar panel support frame, the mobile solar power station can maintain the lowest possible overall weight. This combination of durability, efficiency, and functionality makes it a dependable solution for modern agricultural robotics. The material chosen for this purpose is the lightweight and robust heat treated and artificially aged aluminum alloy EN-AW 6082-T6 [10], which meets the necessary strength and weight requirements. Using lightweight materials in renewable energy stations offers significant sustainability benefits, such as reduced material usage, improved fuel efficiency, and lower carbon emissions. However, achieving the right balance between strength and weight is important to find. This study examines the design and welding processes for a mobile solar power station, emphasizing the importance of simulations applied to structure and the impact of welding temperatures on material properties.

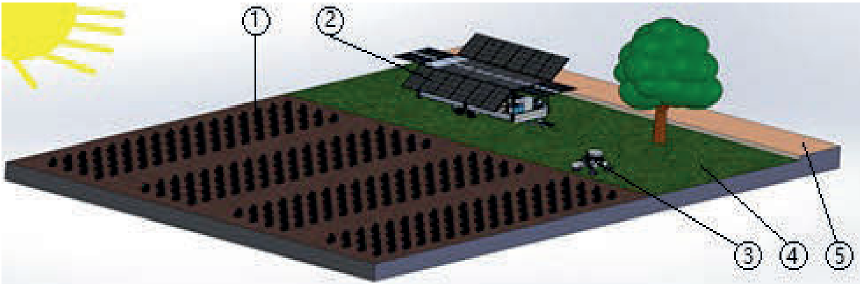

Fig. 1. Fragment of a field: 1- field; 2- mobile power station; 3- field robot; 4- service area; 5- road.

The article aims to provide practical insights into selecting the right production methods, techniques and technologies to ensure the durability and functionality of the structure. The design focuses on creating a lightweight yet strong structure that supports the main framework as well as solar panel mounting and tracking system.

It also provides practical insights into welding methods and structural simulations using SolidWorks Finite Element Method (FEM) to evaluate structural performance under wind loads.

This study contributes to developing an efficient and sustainable mobile energy solution for agricultural applications. Mobile power station serves as a fully functional service unit.

2. Dynamic Loads and Forces

Power station has to be easily transportable; energy has to be brought to the location to meet energy needs of agricultural robots. The mobile solar power station is subjected to various dynamic forces during transport and operation. On the road, the station experiences longitudinal forces from acceleration and braking, lateral forces from cornering and crosswinds, and vertical forces caused by road surface irregularities. These forces impact the structural integrity of the station, making it important to design the frames to withstand these conditions while keeping the overall weight low to improve transport efficiency and reduce environmental impact.

During transportation, forces from road irregularities, such as bumps and potholes, as well as changes in speed, cause vibrations and shocks that propagate through the structure. The large surfaces and side panels are particularly vulnerable to wind-induced loads, which can create significant tension for structure. These forces are concentrated at specific areas, which must be thoroughly analyzed to ensure the structure can withstand the stresses experienced during transportation as well as in working configuration.

Mobile power stations, characterized by their large surfaces and side panels, are exposed to significant wind loads, which can create concentrated forces on the structure. Understanding these forces is essential to ensure the structural integrity and functionality of the power station. It is critical to analyze the impact of wind loads, as higher wind speeds result in increased pressure on the station's surfaces, potentially leading to structural stress and deformation. Figure 2 illustrates how wind loads are applied to the mobile power station structure during operation when panels are inclined at 45 degrees, highlighting the large surface area exposed to wind forces. Furthermore, Fig. 2 illustrates the interaction of these forces with the structure, highlighting the significance of assessing structural integrity in these conditions.

A key feature of the station is the ability to rotate its solar panel-equipped sides around their axis, increasing efficiency. This is a significant increase in energy caption within a small footprint. During operation, all sides can be parallel with the ground. However, as the panels move, their large surface area is exposed to wind forces as seen in Fig. 2.

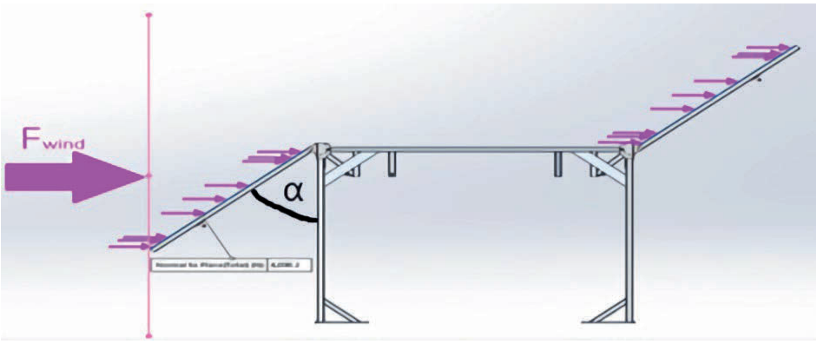

Fig. 2. Wind force (4098.2 N) applied to mobile power station large surface areas.

Dynamic loads, particularly those caused by wind, are a significant concern for mobile power station. The large surfaces of the station are subjected to substantial wind rising up to 16–20 m/s induced forces in Baltic region [11], which can create concentrated stress points and increase the risk of structural failure. Analyzing these forces is crucial to prevent damage and ensure the reliability of the power station during transportation and operation. By assessing the impact of wind loads, the design can be optimized to withstand these forces, ensuring the station's safety and durability in various environmental conditions. Wind load can be calculated using the formula (1) [12]:

$$F_{\text{wind}} = \frac{1}{2} \cdot \rho \cdot v^2 \cdot A \cdot C_{\text{d}}, \tag{1}$$

where

F_{wind} wind forces on the mobile solar station's surface, N;
ρ air density, kg/m^3;
v wind speed, m/s;
A mobile power station's open to wind surface, m^2;
C_{d} drag coefficient (depends on the shape and angle of the surface).

Structural analyses have been conducted to assess the impact of dynamic forces on the station. These evaluations focus on identifying stress concentrations and optimizing the distribution of loads across the structure [3]. The design process for sun-tracking system must account for maximum wind forces at all possible panel angles (Fig. 3 and Table 1).

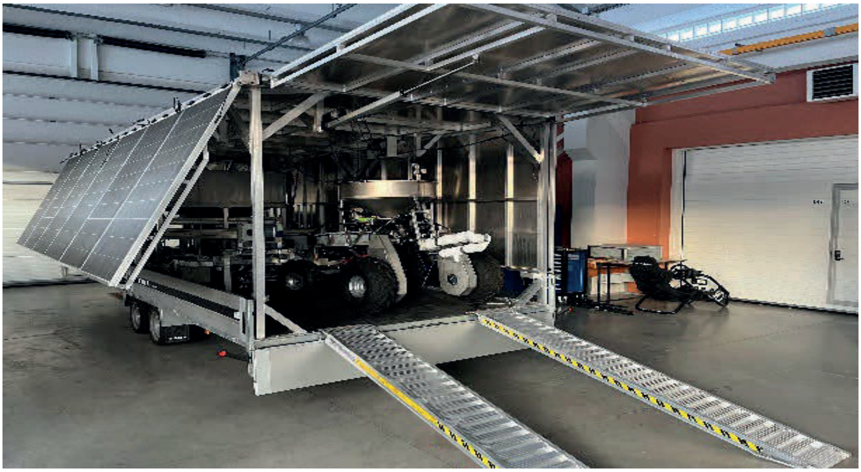

Fig. 3. Mobile power station with open surfaces.

TABLE 1. WIND FORCE AT DIFFERENT PANEL ANGLES

Panel angle α, °	Drag coefficient $C_d = \sin(\alpha)$	Wind force F_{wind}, N
10	0.174	1006.6
15	0.259	1499.5
30	0.500	2894.1
45	0.707	4092.8
90	1.000	5788.1

The wind incidence angle significantly impacts wind load on sun-tracking systems. At 90° (panels perpendicular to wind), wind forces peak at 5788.1 N (30 m/s), while at 10° (panels parallel to wind), forces drop to 1006.6 N.

The structural framework of the mobile power station is constructed from heat-treated and artificially aged aluminum alloy 6082-T6, which provides the necessary strength while maintaining a low total weight [13]. However, welding or exposure to high temperatures during manufacturing can alter the mechanical properties of 6082-T6, such as reducing its tensile strength and hardness in the heat-affected zone [14] (HAZ). Changes in metallurgy must be understood and carefully managed to ensure the structure retains its durability and performance under operational loads and during transportation. Despite these challenges, the lightweight nature of EN-AW 6082-T6 reduces fuel consumption during transport and contributes to environmental sustainability.

The use of lightweight materials like EN-AW 6082-T6, combined with structural optimization, supports the transport and operational requirements of the power station while minimizing environmental impact. A lower overall mass improves transport efficiency and reduces material consumption during production, aligning with sustainability goals. By addressing the effects of welding and high temperatures on the material, the design ensures the station remains both durable and efficient, meeting the requirements for a mobile power station.

3. Materials and Methodology

To design a mobile power station, understanding the effects of welding on heat-treated aluminum alloys is important. Challenges in aluminum welding is porosity formation and microstructural issues such as porosities, cracks, coarse grains [15]. The test specimens were obtained from butt-welded connections situated beneath the solar panel mounting surfaces, as these locations experience the most significant stress concentrations under operational wind loading conditions. These specific joints were selected for destructive testing due to their large surfaces open to wind conducted forces.

SolidWorks software is chosen for its computational efficiency for linear static stress analyses, verified material libraries for heat treated aluminum alloy and seamless integration with the station's CAD model. While alternatives like ANSYS software (for nonlinear dynamics and heavy complex models) and COMSOL (multiphysics). SolidWorks provided sufficient accuracy for structural analysis while maintaining workflow without importing software.

Order for performing experimental test: laser welding, CNC milling, destructive test with Instron 5969, microscope analysis of defects.

Welding of test specimen done with CS-FL3000 fiber laser welder (1080 nm, 3 kW max) with FWS-01A automatic wire feeder. Cutting the towing hitch using Haas MiniMill CNC. Tracking the elongation using Instron 5969 with 50 kN load cell for destructive pull test of the test specimen. Mitutojo TM-510 microscope for elongation tracking

The tests followed the standards EVS-EN ISO 4136:2022 and EVS-EN ISO 6892-1:2019. Specimens were prepared with a working width of 12 mm, gripping width of 24 mm, and total length of 202.5 mm, cut using a Haas MiniMill CNC milling machine for precision, see Fig. 4.

Tensile tests were performed using an Instron 5969 universal testing machine, see Fig. 5, with a 50 kN load cell, applying a controlled loading rate of 15 MPa/s until failure. Specimen dimensions were measured at multiple points, and elongation was assessed using a Mitutoyo TM-510 measuring microscope.

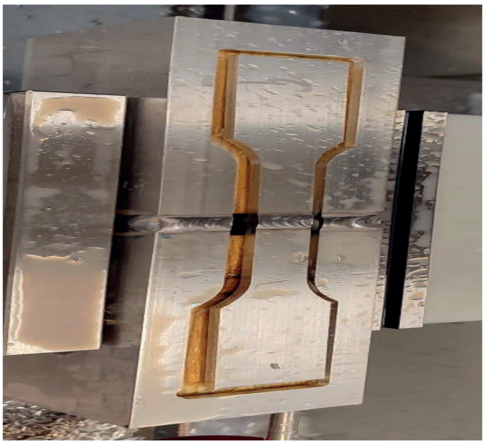

Fig. 4. Cutting the towing hitch.

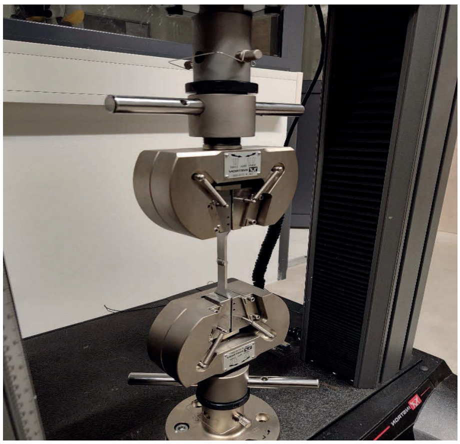

Fig. 5. The towing hitch installed in the Instron 5969 testing machine.

The tensile tests were conducted on specimens welded using Tungsten inert gas (TIG) welding with filler material and filler-free laser welding, to compare their effects on material properties. The laser-welded test specimens were welded using a CS-FL3000 model laser welding machine manufactured by JNCSlaser. The welding machine was equipped with a fiber laser source with a light wavelength of 1080 nm and a maximum power output of 3000 W. For welding tests involving filler material, an automatic wire feeder, model FWS-01A, was additionally used to supply the welding wire.

Referred research was conducted using different filler materials in welding result in various grain growth depending on the filler material, resulting in different output [16] The results indicated that laser welding, due to its lower heat input, provided better mechanical properties by minimizing thermal distortion and preserving the structural integrity of the aluminum alloy. In contrast, traditional TIG welding, while effective, resulted in greater thermal distortion and a larger heat-affected zone, leading to a reduction in overall mechanical performance down to 40% [17]. However, integrating flux backing tape to welds resulted in positive effect while measuring tensile strength in the same destructive method [18]. Using laser welding technology results in minimized thermal input, meaning that residual stresses in the base material are reduced.

Minimized heat input prevents structural deformations and tensions in the base material [19]. FEM simulations were conducted in SolidWorks to analyze wind-induced stresses on the structure. Input parameters included material properties from destructive tests as shown in Table 2 and wind load data taken from Table 1. Simulations validated stress distribution under maximum wind loads up to 30 m/s, ensuring the structure could withstand dynamic forces without exceeding the welded material's tensile strength limit from destructive test result 186.73 MPa.

TABLE 2. LASER WELDED DESTRUCTIVE TEST RESULTS

Test specimen	Tensile strength R_m, MPa	Yield strength $R_{p0.2}$, MPa	Elongation A, %
Welded 1	192.5	131.7	2.91
Welded 2	188	137	3.87
Welded 3	179.9	130.3	2.61
Welded 4	184.6	134.3	2.17
Welded 5	180.3	129.2	3.8
Welded 6	182.8	131.1	2.22
Welded 7	99.5	96.4	1.93
Welded 8	190.3	130.6	3.1
Welded 9	191.6	129	3.39
Welded 10	190.6	127.1	3.26
Welded 11	148.3	131.2	2.24
Average	186.73	131.14	3.04

4. RESULTS

The study focused on the design and evaluation of a mobile solar power station intended to meet the energy requirements of agricultural robots, particularly in remote and off-grid environments. The purpose of this study is to understand changes in metallurgy and material's mechanical properties that occur in heat treated aluminum alloy EN-AW 6082-T6 after welding.

Tensile tests were carried out on EN-AW 6082-T6 aluminum alloy to assess the differences between laser welded and unwelded specimens. Eleven tensile tests were performed on filler-free laser-welded specimens, one specimen with a weld seam crack was excluded from the average calculations, the results are shown in Table 3. The average tensile strength was 186.73 MPa, yield strength was 131.14 MPa, and elongation at fracture was 3.04 %.

Five tensile tests were conducted on unwelded EN-AW 6082-T6 material, see Table 3. The average tensile strength was 289.45 MPa, yield strength was 245.23 MPa, and elongation at fracture was 12.78 %. These values align with the certified material properties (tensile strength: 290 MPa, yield strength: 250 MPa, elongation: 8 %).

TABLE 3. UNWELDED MATERIAL DESTRUCTIVE TEST RESULTS

Test specimen	**Tensile strength R_m, MPa**	**Yield strength $R_{p0.2}$, MPa**	**Elongation A, %**
Unwelded 1	296.4	259.2	11.5
Unwelded 2	289.2	243.8	14.06
Unwelded 3	287.3	241.1	–
Unwelded 4	284.9	236.8	–
Average	289.45	245.23	12.78
Certificate	290	250	8

The destructive tests focused on evaluating the yield strength of butt-welded joints in heat-treated aluminum alloy EN-AW 6082-T6. The average yield strength of the unwelded material was 245.23 MPa, while the welded specimens showed an average yield strength of 131.14 MPa.

This represents a reduction of approximately 46.5 % in yield strength after welding. The tensile strength also decreased by 35.5 %, from 289.45 MPa to 186.73 MPa. For higher tensile strength results in destructive test controlling power density of laser weld and modifying the beam shape as well as controlling welding thermal cycles can help to achieve higher tensile strength values [20]. Another study combined welding wire and preplaced Al-Si powder to improve laser welded joint quality [21]. During current study results indicate that welding significantly reduces the material's mechanical properties, with plastic deformation occurring earlier and fracture stress being lower than in the unwelded base material [19]. The test results were used as input for FEM simulations in SolidWorks, ensuring the mobile power station's design could withstand dynamic loads without exceeding the material's tensile strength limit of 186.73 MPa. Exceeding this limit could lead to permanent deformation or fracture, compromising the station's functionality.

At high wind speeds, significant pressure is exerted on the large surface areas of the mobile power station, particularly when the long sun-tracking side is perpendicular to the wind (90°). This creates tension that must be carefully assessed to ensure structural integrity.

The simulations confirmed that stresses should not exceed 186.73 MPa, the tensile strength limit derived from destructive tests. The reverse engineering method validated the simulation results, ensuring accurate modeling of the material's behavior under load.

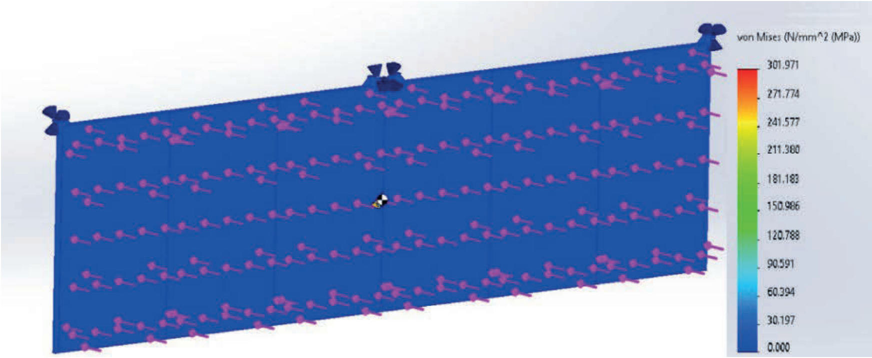

Fig. 6. Mobile power station's long side under wind load: 302 MPa.

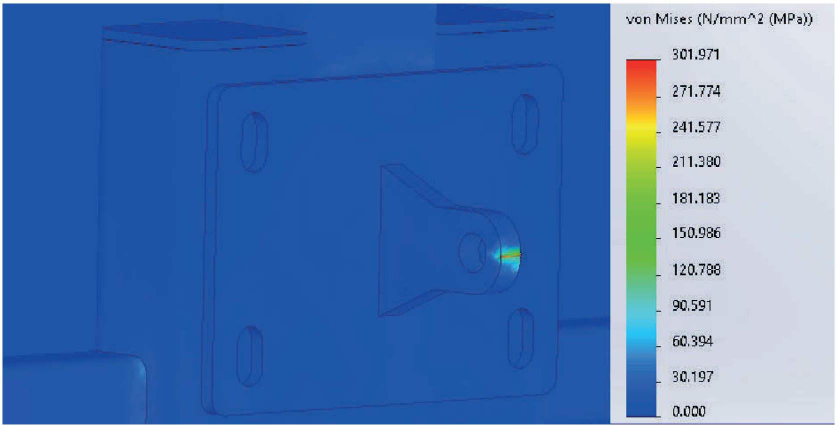

Fig. 7. Sun-tracking system's actuator mounting stainless steel bracket under load: 302 MPa.

Since the stress value obtained from simulations exceeds 186 MPa, as determined by real-life destructive testing, the use of EN-AW 6082T6 aluminum alloy is not feasible, as it risks surpassing the material's tensile strength. Instead, stainless steel is a more suitable material for the actuator mounting brackets. The wind-induced load on the surface, calculated for a wind speed of 30 m/s, combined with the gravitational force of six solar panels (totaling 294.3 N), resulted in a total force of 6082.4 N when the panels were positioned perpendicular to the wind (90°) as depicted in Fig. 6. Stress arises in the material due to the small load-bearing surface area of the sun-tracking system's actuator mounting points. The significant wind-induced load is transferred to the actuator connection points, where a tensile stress of 320 MPa is generated under heavy wind load to a small surface area.

SolidWorks FEM simulation of wind load stress distribution on the long side actuator's fixing bracket is shown in Fig. 7, stresses exceeding 186 MPa indicate the need for stainless steel brackets force simulated to the EN-AW 6082T6 construction did not exceed over 186.73 MPa, resulting in elastic deformation of the structure.

The FEM simulations analyzed wind-induced pressure distribution across the station's large surface areas, considering the material's mechanical properties. By evaluating stress distribution, the simulations ensured the structure could withstand dynamic wind forces during operation without failure. This analysis provided insights into the design and reinforcement of the solar power station, ensuring its reliability under real-world conditions.

The mobile power station is equipped with an integrated automation system that folds the solar panel wings when wind speeds reach 15 m/s. At this wind speed, the force acting on the long side of the station would result in force of 1523 N. Automation system ensures the structure is not exposed to maximum loads, reducing the impact of strong winds and extending the system's operational lifespan. By implementing this feature, a safety factor is achieved, ensuring the station's reliability and safety even under extreme weather conditions.

The unwelded material exhibited an average tensile strength of 289.45 MPa and a yield strength of 245.23 MPa, which closely matched the certified material properties. In comparison, laser-welded specimens showed reduced tensile strength (186.73 MPa) and yield strength (131.14 MPa), corresponding to reductions of 35.5 % and 46.5 %. Laser welding, due to its lower heat input, minimized thermal distortion and preserved the material's structural integrity more effectively than TIG welding method. Wind load analysis revealed that the station's large surface areas were susceptible to significant forces, especially when solar panels were positioned perpendicular to the wind (90°). At a wind speed of 30 m/s, the forces reached a peak of 5788.1 N, while at a 10° angle, the forces decreased to 1006.6 N. Finite Element Method simulations confirmed that the structure could endure these dynamic loads without surpassing the material's tensile strength limit of 186.73 MPa, ensuring its structural integrity during operation. The lightweight aluminum alloy 6082-T6, combined with laser welding techniques, provided a suitable balance of strength and weight for the mobile power station. This analysis provided critical insights into the design and reinforcement of the solar power station, ensuring its reliability and durability under operational conditions. The reverse engineering method enhanced the structure's ability to withstand calculated and simulated wind force.

5. Conclusion

The mobile solar power station addresses the challenge of providing reliable electricity in rural and off-grid areas, where access to traditional energy infrastructure is often limited. It integrates energy production, storage, and management to ensure a continuous power supply for agricultural robots and other applications, eliminating the need for external energy sources.

The station is designed as a multifunctional resource supply system for agricultural robots, incorporating energy storage, battery management, and automated refueling mechanisms. This design ensures the robot has access to essential resources, such as power and fertilizers, without manual intervention, enabling efficient and autonomous operation for autonomous field robot.

The study demonstrated the feasibility of a mobile solar power station designed to support agricultural robots in remote and off-grid locations. The use of EN-AW 6082-T6 aluminum alloy, paired with laser welding, resulted in a lightweight yet durable structure. Laser welding effectively minimized thermal distortion and residual stresses, preserving the material's mechanical properties compared with other welding technologies. FEM analysis has been conducted to sun-tracking large surface areas to understand its structural integrity to withstand dynamic loads caused by wind forces. Automation system folds sun-tracking panels when wind exceeds at the speed of 15 m/s.

The lightweight design reduced fuel consumption during transport and minimized material usage, contributing to environmental sustainability. The integration of a solar tracking system improved energy capture efficiency, ensuring a consistent and reliable energy supply for agricultural robots. The mobile power station provides a self-sufficient energy solution, enabling uninterrupted field operations in remote areas. The design considerations, including material selection, welding techniques, and structural analysis, offer valuable insights for the development of similar renewable energy systems.

In summary, this study highlights the importance of integrating material science, welding technology to create sustainable mobile power station. The findings contribute to advancing renewable energy systems for agricultural and remote applications, ensuring reliability and performance under real-world conditions. The mobile solar power station represents a practical and sustainable solution for meeting the energy needs of modern agricultural robotics in remote areas.

ACKNOWLEDGEMENT

Funder: Estonian Research Council Foundation, project: EAG304 "Autonomous transportable energy production station".

REFERENCES

[1] Kuaban G. S., Gelenbe E., Czachórski T., Czekalski P. Modelling the Energy Performance of Off-Grid Sustainable Green Cellular Base Stations. *IEEE 4th Asian Conference on Innovation in Technology (ASIANCON)* 2024. https://doi.org/10.1109/MASCOTS59514.2023.10387661

[2] Candra O., Chammam A., Rahardja U., Ramirez-Coronel A., Al-Jaleel A., Al-Kharsan I. H., Muda I., Derakhshani G., Rezai M. M. Optimal Participation of the Renewable Energy in Microgrids with Load Management Strategy. *Environmental and Climate Technologies* 2023:27(1):56–66. https://doi.org/10.2478/rtuect-2023-0005

[3] Zadeh D. R., Derakhshan G., Hakimi S. M., Abdi B. An economic and environmental optimization model in a micro grid with demand response. *Environmental and Climate Technologies* 2022:26(1):730–741. https://doi.org/10.2478/rtuect-2022-0056

[4] Eissa M. A., Chen P. Design and Cost Analysis for a Second-life Battery-integrated Photovoltaic Solar Container for Rural Electric Vehicle Charging. *IFAC-PapersOnLine* 2024:58(28):1085–1090. https://doi.org/10.1016/j.ifacol.2025.01.141

[5] Ali-Karaghouli A., Kazmerski L. L. Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. *Solar Energy* 2010:84(4):710–714. https://doi.org/10.1016/j.solener.2010.01.024

[6] Augustyn G., Mikulik J., Rumin R., Szyba M. Energy Self-Sufficient Livestock Farm as the Example of Agricultural Hybrid Off-Grid System. *Energies* 2021:14(21):7041. https://doi.org/10.3390/en14217041

[7] Soots K., Lillerand T., Jõgi E., Virro I., Olt J. Feasibility analysis of cultivated berry field layout for automated cultivation. *20th International Scientific Conference - Engineering for Rural Development* 2021:1003–1008. https://doi.org/10.22616/ERDev.2021.20.TF222

[8] Olt J., Liivapuu O., Virro I., Lillerand T. Designing a Fertilizing Robot Application Considering Energy Efficiency. *Environmental and Climate Technologies* 2024:28(1):258–268. https://doi.org/10.2478/rtuect-2024-0021

[9] Awasthi A., Shukla A. K., S.R. Murali Manohar, Dondariya C., Shukla K. N., Porwal D., Richhariya G. Review on Sun Tracking Technology in Solar PV System. *Energy Reports* 2020:6:392–405. https://doi.org/10.1016/j.egyr.2020.02.004

[10] Xu X., Zhu W., Guo X., Liang C., Deng Y. Effect of Ageing Treatment Process on the Microstructure Development and Mechanical Properties of 6082 Al Alloy. *Journal of Alloys and Compounds* 2023:935(1):167892. https://doi.org/10.1016/j.jallcom.2022.167892

[11] Long-term Statistics of Atmospheric Conditions over the Baltic Sea and Meteorological Features Related to Wind Wave Extremes in the Gulf of Gdańsk. *Oceanologia* 2024:66(2):180–195. https://doi.org/10.1016/j.oceano.2023.10.002

[12] Holmes J. D. Wind Loading of Structures. Second Edition. London: Taylor & Francis, 2007.

[13] Georgantzia E., Gkantou M., Kamaris G. S. Aluminium Alloys as Structural Material: A Review of Research. *Engineering Structures* 2021:227:111372. https://doi.org/10.1016/j.engstruct.2020.111372

[14] Missori S., Sili A. Mechanical Behaviour of 6082-T6 Aluminium Alloy Welds. *Metallurgical Science and Technology* 2000:18(1).

[15] Li S., Mi G., Wang C. A Study on Laser Beam Oscillating Welding Characteristics for the 5083 Aluminum Alloy: Morphology, Microstructure, and Mechanical Properties. *Journal of Manufacturing Processes* 2020:53:12–20. https://doi.org/10.1016/j.jmapro.2020.01.018

[16] Alzahrani B., Ahmed M. M. Z., Habba M. I. A., Fouad R. A., Elshaghoul Y. G. Y., Gadallah E. A. TIG Welding of EN AW-6082 Al Alloy: A Comparative Analysis of Filler Rods on Microstructural and Mechanical Performance. *Journal of Manufacturing and Materials Processing* 2025:9(1):21. https://doi.org/10.3390/jmmp9010021

[17] Ma B., Gao X. D., Huang Y., Gao P. P., Zhang Y. A Review of Laser Welding for Aluminium and Copper Dissimilar Metals. *Optics & Laser Technology* 2023:167:109721. https://doi.org/10.1016/j.optlastec.2023.109721

[18] Mannapovich S. R., Touileb K. Improving the Formation and Quality of Weld Joints on Aluminium Alloys during TIG Welding Using Flux Backing Tape. *Metals* 2024:14(3):321. https://doi.org/10.3390/met14030321

[19] Yang S., Wang Y., Yang X., Lu X., Li M. V., Zhu X. Effect of Softening of 6082-T6 Aluminum Alloy CMT Welded Joints on Mechanical Properties and Fracture Behavior. *Journal of Manufacturing Processes* 2024:124:1567–1582. https://doi.org/10.1016/j.jmapro.2024.07.046

[20] Wallerstein D., Salminen A., Lusquiños F., Comesaña R., García J. d. V.., Rodríguez A. R., Badaoui A., Pou J. Recent Developments in Laser Welding of Aluminum Alloys to Steel. *Metals* 2021:11(4):622. https://doi.org/10.3390/met11040622

[21] Li S., Mi G., Wang C. A Study on Laser Beam Oscillating Welding Characteristics for the 5083 Aluminum Alloy: Morphology, Microstructure, and Mechanical Properties. *Journal of Manufacturing Processes* 2020:53:12–20. https://doi.org/10.1016/j.jmapro.2020.01.018