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DESIGN AND CONSTRUCTION OF A LAB-SCALE BRIQUETTE PRESS FRAME STRUCTURE

Tony Siagian[1], Muhammad Asyfa[2*], Tengku Jukdin Saktisahdan[3], Intan Zahar[4], Ali Hasimi Pane[5]

[1] Mechanical Engineering, Faculty of Engineering and Computer Science, Universitas Pembinaan Masyarakat Indonesia, Jl. SM. Raja Km 9/Jl. Balai Desa Pasar 12 Marindal II, Kota Medan, Sumatera Utara

[2,3,4,5] Mechanical Engineering, Faculty of Engineering, Universitas Asahan, Jl. Latsitarda, Tj. Morawa A, Kabupaten Asahan, Sumatera Utara

Email: *muhammadassyifa85@gmail.com

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Abstract

The increasing global energy demand and high dependence on fossil fuels have encouraged the development of biomass-based alternative energy through briquetting technology. However, research on the structural frame design of laboratory-scale briquette press machines remains limited, particularly regarding structural strength validation using engineering analysis approaches. **This study aims** to design and analyze the structural strength of a hydraulic-based briquette press frame for laboratory applications. **The research gap** lies in the limited integration of structural analysis, safety factor evaluation, and frame optimization in small-scale briquette machines. **The novelty** of this study is the development of an ASTM A36-based frame using an integrative approach involving Computer Aided Design (CAD), stress analysis, buckling, and fatigue evaluation under pressure variations of 1000–1600 psi. **The research method** employed an experimental design and build approach combined with structural simulations and hydraulic pressure testing. **The results** showed that the maximum stress of 17.24 MPa remained far below the yield strength of ASTM A36 material, with a fatigue safety factor of 14.5, indicating that the structure is safe, elastic, and suitable for laboratory-scale biomass research applications.

Abstrak

Peningkatan kebutuhan energi global dan tingginya ketergantungan terhadap bahan bakar fosil mendorong pengembangan energi alternatif berbasis biomassa melalui teknologi briket. Namun, penelitian mengenai desain struktur rangka mesin pencetak briket skala laboratorium masih terbatas, khususnya pada validasi kekuatan struktur menggunakan pendekatan analisis teknik. **Penelitian ini bertujuan** merancang dan menganalisis kekuatan rangka mesin pencetak briket berbasis sistem hidrolik untuk aplikasi laboratorium. **Gap penelitian** terletak pada minimnya integrasi analisis struktur, evaluasi faktor keamanan, dan optimasi desain rangka pada mesin briket skala kecil. **Keterbaruan penelitian** ini adalah pengembangan rangka mesin menggunakan material ASTM A36 dengan pendekatan integratif berbasis *Computer Aided Design* (CAD), analisis tegangan, *buckling*, dan *fatigue* pada variasi tekanan 1000–1600 psi. **Metode penelitian** menggunakan pendekatan experimental design and build dengan simulasi dan pengujian struktur terhadap variasi tekanan hidrolik. **Hasil penelitian** menunjukkan bahwa tegangan maksimum

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Kata Kunci: biomassa, mesin briket, analisis struktur

sebesar 17,24 MPa masih berada jauh di bawah batas luluh material ASTM A36, dengan faktor keamanan fatigue sebesar 14,5 sehingga struktur dinyatakan aman, elastis, dan layak digunakan untuk aplikasi laboratorium dan penelitian biomassa berkelanjutan.

INTRODUCTION

The continuously increasing global energy demand in line with population growth and industrial development, coupled with a high dependence on fossil fuels [1], [2], poses serious challenges related to environmental degradation, carbon emissions, and long-term limitations in energy availability, while more than 2.8 billion people worldwide still lack access to electricity and remain heavily dependent on cheap wood-based energy that exacerbates climate change; this situation drives the development of renewable energy alternatives such as biomass, which can be utilized through briquetting technology to convert biomass waste into dense solid briquettes with high energy density [3], [4], good combustion efficiency, as well as ease of transport and storage, supported by various types of presses (manual, hydraulic, screw, roller, and pneumatic) [5], [6] and structural analysis using the finite element method (FEM) [7], [8] to ensure the safety and reliability of the machine frame; the urgency of developing an affordable and efficient laboratory-scale machine has become important to support research, education, and the adoption of biomass briquette technology in communities, while also contributing to sustainable waste management and reducing dependence on fossil fuels [9].

Although widely available, biomass wastes from forestry, agriculture, and agro-industrial activities are often underused and can negatively impact the environment if incinerated outdoors or allowed to decay indiscriminately. [10], [11], [12]. Biomass briquetting is an efficient technique for converting loose, low-density residues into dense solid fuel, improving density, handling, storage, transportation, and combustion efficiency. [13], [14], [15]. Contemporary bioenergy constitutes a significant portion of the worldwide renewable energy supply, underscoring the persistent importance of biomass-based technologies in the shift towards sustainable energy systems. [16], [17], [18]. The quality of briquettes is significantly affected by material and process characteristics such as particle size, moisture content, binder composition, compaction pressure, temperature, and pressing time. [19], [20]. Prior research has highlighted the significance of laboratory-scale and small-scale briquetting machines for assessing biomass properties, refining pressing parameters, and enhancing machine efficacy. [21], [22], [23].

Consequently, the frame's design must account for structural integrity, stiffness, load distribution, material selection, joint arrangement, manufacturability, and maintenance accessibility. [24], [25]. Recent research on machine development indicates that the main frame and mold are typically regarded as essential structural subsystems in the design of briquette presses.

Research Urgency

In developing countries, research output is limited due to factors such as unreliable electricity supply and inadequate laboratory equipment [21], [26]. The high cost of purchasing finished equipment and the unavailability of accessories for further imported equipment, contribute to this problem. Biomass densification machines are designed and constructed to address these challenges for teaching and research purposes.

The development of a laboratory-scale briquetting machine is crucial to support academic institutions, researchers, and students in utilizing the potential of biomass through the densification process without the obstacles posed by the creation of equipment [26]. The available machines demonstrate satisfactory performance because the properties of the resulting briquettes meet the ISO Standard (17225). This development will also facilitate hands-on student learning by providing an accessible and reliable platform, allowing institutions to integrate solid

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fuel production experiments into their curricula, fostering a comprehensive understanding of renewable energy solutions, and supporting sustainable practices.

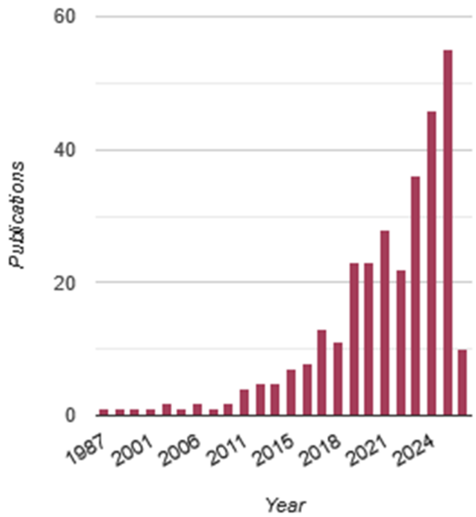

Figure 1. Publications by year

State of the art

Biomass briquetting is a densification technology that compacts loose biomass particles using mechanical pressure to form solid biofuels with improved physical and energy properties [27]. The process parameters that significantly influence briquette quality include compaction pressure, particle size, moisture content, temperature, and binder concentration [28]. Research has demonstrated that optimized briquetting parameters can produce briquettes with calorific values reaching 20.96 MJ/kg and mechanical durability exceeding 95% [29].

Various biomass feedstocks have been investigated for briquette production, including agricultural residues such as rice straw, coffee husks, sawdust, and fruit processing waste [30]. The densification of bean stalks under pressures ranging from 27 to 47 MPa and temperatures up to 90°C has shown significant improvements in mechanical durability [31]. Similarly, studies on oil palm empty fruit bunches revealed that optimal parameters, including 8% moisture content and 26.6 seconds compaction time, meet international standards for biomass briquettes.

Briquette press machines can be categorized based on their operating mechanism into hydraulic piston press, screw extruder, mechanical lever press, roller press, and manual press systems [32]. Hydraulic piston presses are widely preferred for laboratory and small-scale applications due to their ability to generate high compaction pressures with relatively simple construction. The primary components of a hydraulic briquette machine include the hydraulic jack, frame structure, pistons, compression cylinders, and ejection mechanism.

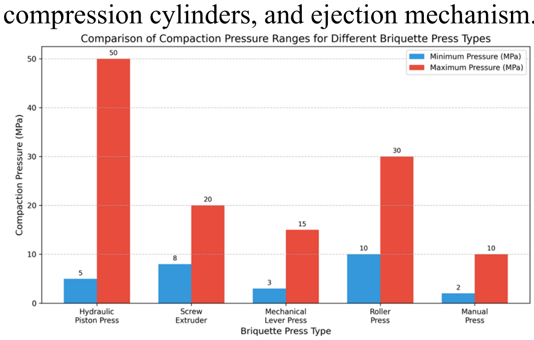

Figure 2. Comparison of compaction pressure ranges for different briquette press types (Data compiled from multiple sources [32]).

Research Gap

Based on a comprehensive literature review, several research gaps can be identified:

Table 1. Research Gap

No	Aspect	Current Condition	Identified Gapsi
1	Structural Analysis	FEM is widely applied to conventional press machines	The lack of FEM analysis specific to biomass briquette machine frames at the MSME scale
2	System Integration	Conventional briquette machine without an automatic safety system	Lack of integration between sensor-based security systems and automatic cleaning mechanisms
3	Experimental Validation	FEM simulation is rarely	The gap between simulation

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		validated with experimental testing	results and actual machine performance
4	Modular Design	Desain mesin briket cenderung rigid	There has been no research on modular design optimization that takes production flexibility into account.
5	Local Material	Use of standard materials (ASTM A36, SS304)	Lack of exploration of more economical local alternative materials

Studies show that several frame designs still approach the material yield stress limit. For example, analysis of the container skid frame shows a maximum stress of 249.921 MPa, which nearly reaches the yield stress of ASTM A36 material (250 MPa) with a minimum safety factor of 0.6, indicating that the design requires optimization.[33]. A similar situation also occurs in the analysis of the UCAV wing structure, which shows a maximum stress of 566.83 MPa with a safety factor of 0.67, far below the acceptable threshold of 1.8 [32].

Previous studies have also shown that conventional briquette machines still have limitations in terms of operational safety and production efficiency [34]. The development of a hydraulic briquette press system with the integration of a pressure sensor-based safety system and an automatic pneumatic cleaning mechanism is an innovation that is still limited in its application.

Research Novelty

Development and structural analysis of the frame of a laboratory-scale briquette machine based on a hydraulic system specifically designed for educational and biomass research applications, with an integrative approach combining CAD design, structural strength analysis, and evaluation of the safety factor at working pressure variations of 1000–1600 psi. Unlike previous studies, which generally focused solely on briquette performance outcomes or conventional machine designs without in-depth structural validation, this research presents frame optimization using ASTM A36 material with an engineering design approach that comprehensively considers load distribution, tensile stress, material safety factor, buckling, and fatigue. In addition, this study offers a frame configuration that is safer, more economical, and feasible for laboratory-scale applications with a maximum stress value of only 17.24 MPa and a high safety factor, thus providing a new contribution to the development of efficient, durable biomass briquette machines and supporting the implementation of sustainable, renewable energy.

RESEARCH METHODS

This study utilizes an experimental engineering methodology, concentrating on the design and evaluation of the structural framework for a hydraulic jack-operated briquette molding machine. This methodology was selected due to the study's emphasis on the design and building process, structural integrity modeling, and performance evaluation of the engineered machine. The study design was executed methodically in many phases, including the identification of structural requirements, selection of frame type and form, determination of materials, modeling with CAD software, and validation of design outcomes by mechanical testing.

Figure 3. Briquette Mould

Research Sample

The research population covers all structural components that form part of the briquette moulding machine, whilst the research sample focuses on the main frame structure, which serves as the support for the hydraulic pressing system. The selection of the sample is based on the critical role of these elements in the stability and strength of the machine. The sample was tested through load simulations and actual testing to determine the frame's ability to withstand compressive forces during the briquette moulding process.

Figure 4. Briquette Sample

Research Procedure

The research process begins with the identification of design requirements based on the equipment's function and workload. These requirements include an analysis of the types of static and dynamic loads that will act on the structure. Subsequently, the most efficient frame configuration for load distribution is selected; in this case, a truss configuration was chosen due to its high strength and relatively economical use of materials. The next stage involves modelling the design in CAD (Computer Aided Design) software to produce three-dimensional visualisations and structural strength simulations. The modelling is carried out with precision to ensure dimensional accuracy and correct joint locations between components. Once the design is finalised, the structural dimensions and materials are specified, taking into account tensile strength, compressive strength, density, and material availability. The fabrication process involves cutting, joining, and assembling structural elements using equipment such as electric welding machines, angle grinders, hand drills, and precision measuring instruments. The final stage involves testing the frame structure, during which a compressive load is applied using a hydraulic jack fitted with a pressure gauge to monitor the pressure level. The test results are used to assess the frame's strength and stability against the compressive forces generated during the briquette moulding process.

RESULTS AND DISCUSSION

The structural analysis of the hydraulic jack-based briquette mould frame was calculated for three pressure variations: 1000 psi, 1300 psi, and 1600 psi. The main parameters calculated include the total force resulting from fluid pressure, the force acting on each push rod, axial stress, and safety factors against yield, buckling, and fatigue. The results of the calculations are shown in Table 1, which indicates that an increase in working pressure results in an increase in compressive force and bar stress, as well as a decrease in the safety factor.

Table 2. Structural Strength analysis of the briquette mould frame

Pressure (Psi)	Total Force (N)	Force Per Bar (N)	Bar Tension (Mpa)
1000	8.664,21	2.166,05	10,78
1300	11.263,47	2.815,87	14,01
1600	13.862,74	3.465,69	17,24

Table 2. above shows that as the applied pressure increases, the total force and stress increase linearly. However, even when the pressure is increased to 1600 psi, all stress values remain well below the yield strength of ASTM A36 material (σ_y = 250 MPa), indicating that the structure is operating under elastic and safe conditions. The fatigue safety factor (material FOS) decreases from 23.19 at 1000 psi to 14.50 at 1600 psi, but remains well above the minimum safety limit (FOS ≥ 3). Similarly, the buckling FOS remains very high (≥ 150), indicating that the structure is not at risk of buckling. The fatigue FOS (Factor of Safety) also decreases, yet remains greater than 10, indicating that the structure has a very long fatigue life and is safe for repeated working cycles during the briquette moulding process.

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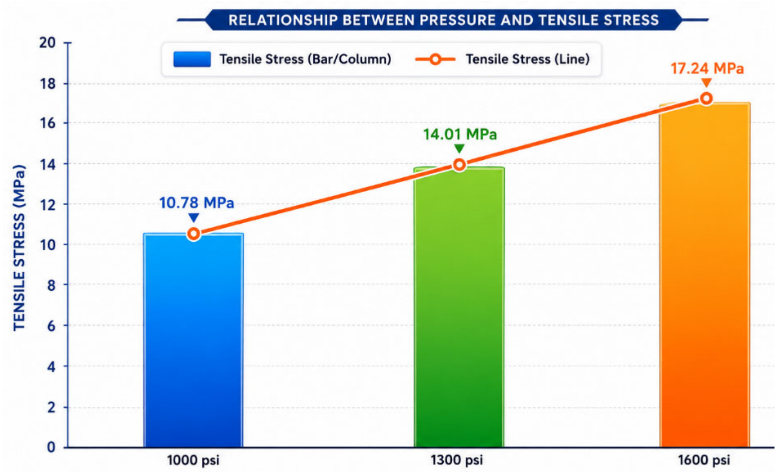

Figure 5. The Relationship between Pressure and Tensile Stress

Figure 5 above shows a graph illustrating the relationship between pressure and tensile stress. The results show that tensile stress increases consistently with increasing pressure. At 1000 psi, the tensile stress is approximately 11 MPa. As the pressure rises to 1300 psi, the tensile stress increases to around 14 MPa, and further increases to approximately 17 MPa at 1600 psi. This trend indicates that higher pressure produces greater tensile loading on the material.

From a mechanical perspective, the increase in tensile stress is associated with the higher internal force generated by elevated pressure. As pressure increases, the material experiences greater stress intensity, which may influence its structural integrity if the stress approaches the allowable strength limit. Therefore, pressure variation should be carefully considered in the design and evaluation process to ensure that the material remains within a safe tensile stress range under operating conditions.

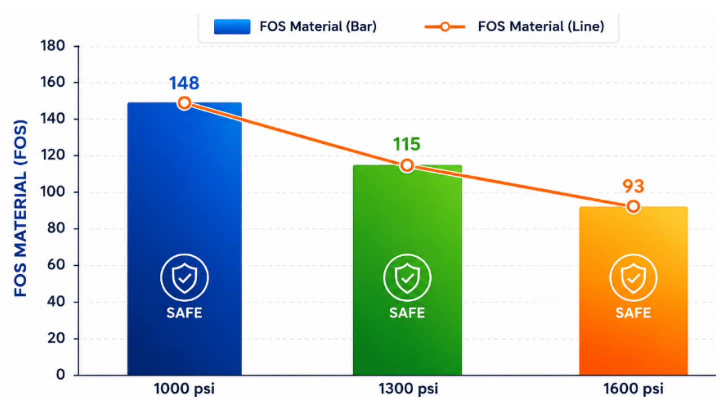

Figure 6. The Relationship between Pressure and FOS Material

The figure 6. The above shows the relationship between pressure and the material's Factor of Safety (FOS). The FOS value decreases as pressure increases, from approximately 148 at 1000 psi, to approximately 115 at 1300 psi, and further to approximately 93 at 1600 psi. These results indicate that an increase in pressure leads to a reduction in the material's safety margin. This occurs because higher pressure generates greater working stress on the material, thereby reducing the material's relative safety capacity under load. Consequently, operating pressure must be carefully controlled and accounted for in the design to ensure the material remains in a safe condition during use.

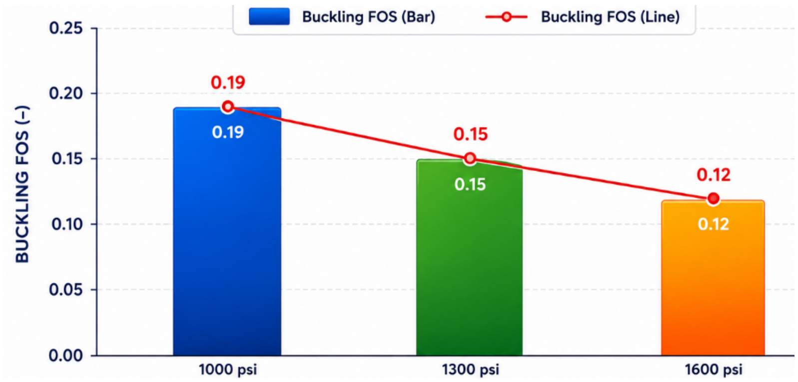

Figure 7. The Relationship between Pressure and FOS Buckling

Figure 7 depicts the relationship between pressure and the buckling Factor of Safety (FOS). The results show a consistent decrease in buckling FOS as the applied pressure increases. At a pressure of 1000 psi, the buckling FOS reaches its highest value, approximately 0.19. When the pressure increases to 1300 psi, the buckling FOS decreases to around 0.15. A further increase in pressure to 1600 psi results in a lower buckling FOS value of approximately 0.12. This trend indicates that higher pressure reduces the structural resistance of the material or component against buckling failure.

From a structural mechanics perspective, the reduction in buckling FOS is associated with the increase in compressive stress induced by higher internal or external pressure. As the applied pressure increases, the structure becomes more vulnerable to instability, resulting in a lower safety margin against buckling. The decreasing trend suggests that pressure is a critical parameter influencing the buckling performance of the structure. Therefore, careful consideration of pressure loading is required in the design process to ensure that the structure maintains adequate stability under operating conditions.

If interpreted using the conventional safety factor criterion, the obtained buckling FOS values, which are below unity, indicate that the structure may not yet satisfy the required stability margin against buckling. Consequently, design improvements such as increasing wall thickness, selecting materials with higher stiffness, optimizing geometry, or adding structural reinforcement may be necessary to improve buckling resistance and ensure safer performance under higher pressure conditions.

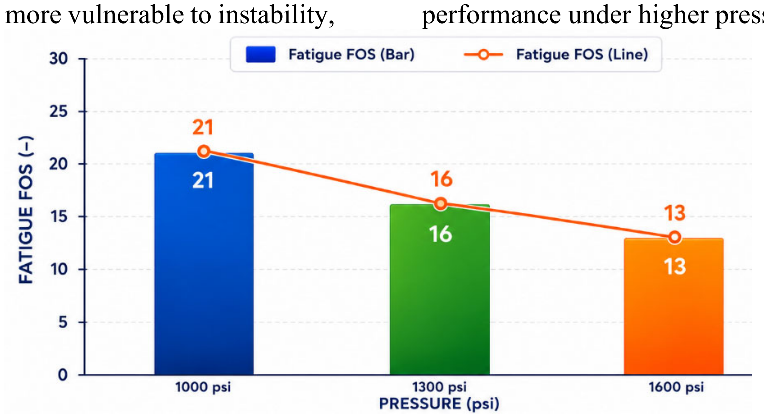

Figure 8. The Relationship between Pressure and FOS Fatigue

Figure 8 presents the relationship between pressure and the fatigue Factor of Safety (FOS). The results indicate that the fatigue FOS decreases as the applied pressure increases. At 1000 psi, the fatigue FOS reaches the highest value, approximately 21. As the pressure increases to 1300 psi, the FOS decreases to around 16, and further declines to approximately

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13 at 1600 psi. This trend demonstrates that higher pressure reduces the fatigue safety margin of the material.

The decrease in fatigue FOS can be attributed to the greater cyclic stress generated under higher pressure conditions. As the pressure increases, the material becomes more susceptible to fatigue damage over repeated loading cycles. However, since all FOS values remain above unity, the material still indicates an adequate safety margin against fatigue failure within the evaluated pressure range. Therefore, although the structure remains relatively safe, the decreasing trend should be considered carefully in design and operational pressure control.

CONCLUSION

This study successfully designed and evaluated a lab-scale hydraulic briquette press frame structure intended to support biomass briquetting experiments under laboratory conditions. The frame was developed using a design-and-build approach, supported by CAD modelling and structural analysis under three hydraulic pressure variations: 1000, 1300, and 1600 psi. The results indicate that increasing hydraulic pressure leads to higher total force, greater force per bar, and increased tensile stress on the frame structure.

The maximum tensile stress was obtained at 1600 psi, reaching 17.24 MPa. This value remains far below the yield strength of ASTM A36 steel, indicating that the frame operates within the elastic region and is structurally safe under the evaluated loading conditions. Although the Factor of Safety decreases as pressure increases, the fatigue safety margin remains adequate for repeated laboratory operation. Therefore, the proposed briquette press frame can be considered safe, reliable, and suitable for laboratory-scale briquette production and experimental testing.

Overall, the developed frame structure provides a practical and efficient platform for supporting renewable energy research, particularly in the development of biomass briquettes as an alternative solid fuel. However, further validation through extended experimental testing, long-term cyclic loading evaluation, and refinement of buckling analysis is recommended to improve the accuracy and reliability of the structural assessment.

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