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DEVELOPMENT OF A MOBILE HYDRAULIC PRESS MACHINE USING FINITE ELEMENT ANALYSIS

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Mobile hydraulic press machines provide significant benefits in field-based applications such as construction, agriculture, and maintenance, all of which mobility and versatility are of utmost importance. The design and development of mobile hydraulic press machines are responsible for these advantages, which can be attributed to them. The primary focus of this study is to evaluate the structural performance of a mobile hydraulic press machine while it is subjected to operational loads. Formulation, modeling, and simulation of the machine are all carried out with the assistance of finite element analysis (FEA). Cutting-edge computer-aided design (CAD) technologies were applied to develop a model of the machine. This model was then analyzed to ascertain essential parameters such as the distribution of stress, the overall deformation, and the safety aspects. The data imply that the hydraulic telescopic cylinder, press machine frame, waste press, and waste press door all perform within an acceptable safety factor larger than two. In addition, the stress levels are lower than 550 MPa, and the deformation values vary from 0.20 mm to 0.40 mm, significantly lower than the standards for the material. When doing the safety factor analysis, it is essential to locate areas that could benefit from a slight strengthening to enhance the product's dependability and durability. In addition, the waste press section had an excessively planned safety margin, which indicated room for improvement in material optimization. The structural integrity of the machine is ensured by this all-encompassing approach, which also provides the machine's efficiency and versatility for various field applications. Future attempts to enhance the concept will focus on prototyping and testing

Keywords: hydraulic press machine, stress distribution, total deformation, structural optimization

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1. Introduction

Metal shaping, punching, bending, and pressing are just a few industrial processes that rely on hydraulic press machines and their enormous force generation capabilities. These devices are based on fluid mechanics, which states that mechanical work can be accomplished by applying pressure to hydraulic fluid. Manufacturing, automotive, and metalworking industries rely on hydraulic presses due to the substantial mechanical advantage this approach provides, which allows even small presses to generate large forces [1]. Hydraulic presses provide exact control over the applied force, essential for forming sheet metal in automobile panels and forging heavy-duty industrial parts [2]. This control helps to reduce material waste and ensures high-quality products.

However, due to their intrinsic designs, conventional hydraulic press machines frequently have limited operational ranges. For the most part, presses are big, unmovable machines that belong in a dedicated space like a workshop or factory. Despite their stellar performance in controlled situations, their immobility renders them useless for on-site or field activities. Pressing, shaping, or molding jobs frequently necessitate working in inaccessible or distant areas in sectors such as construction, maintenance, agriculture, and repair. For instance, in rural locations, it may be necessary to fabricate or repair agricultural equipment parts or bend or straighten steel beams on-site for construction projects.

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Moving bulky parts or equipment to a stationary press wastes time, energy, and money in these situations. Consequently, it is crucial to create a portable hydraulic press machine that can exert the same amount of power and achieve the same level of accuracy as a stationary one [3].

Designing a transportable hydraulic press that is also strong and long-lasting is no easy feat [4, 5]. Additional design constraints brought about by mobility include decreasing the machine's total weight without jeopardizing the structural integrity of its structure and components. The machine needs to be small and efficient to be easily transported while still applying enough power to do pressing jobs. For this reason, the mobile press's safety and efficacy in different settings depend on meticulous attention to detail in frame design [6], material selection [7, 8], and hydraulic component optimization [9, 10].

Nowadays, engineers can optimize the design of intricate mechanical systems before they are physically produced thanks to advanced computational tools and methodologies. In instance, structural analysis and mechanical design have been utterly transformed by Finite Element Analysis (FEA) [11]. By reducing complex mechanical systems and components to their constituent finite elements, engineers may run accurate simulations using finite element analysis (FEA). By applying different loads and boundary conditions to these pieces, it is possible to simulate real-world operating circumstances. In addition to assisting in identifying possible design failure sites, this predictive modeling approach also allows for the optimization of material utilization, reduction of weight, and overall performance improvements [12]. No longer are expensive prototypes and physical tests necessary for engineers to virtually assess a design's structural performance under various stress and load circumstances thanks to finite element analysis (FEA). Therefore, research on the design and simulation of a hydraulic press machine is still relevant.

2. Literature review and problem statement

A hallmark of hydraulic systems is their capacity to transform modest quantities of mechanical energy into hydraulic pressure, producing enormous forces with remarkable efficiency. With their constant improvement thanks to engineers' work, these systems are now essential in various commercial settings. Hydraulic power is beneficial for hydraulic presses, which are used to stamp, mold metal, punch, and forge, all of which are jobs that call for tremendous force. Industries that require accuracy and strength, such as metalworking, aerospace, and the automotive sector, have found hydraulic presses invaluable due to their ability to deliver uniform, regulated power. Among their many applications, hydraulic presses shape metal components like vehicle body panels in the automotive industry, and help produce high-strength materials used in aircraft building in the aerospace sector.

Research [3] on developing and constructing a 5-ton hydraulic press machine is critical for material testing, assembly, and metal forming. However, numerous crucial issues remain unexplored. The hydraulic press's behavior under dynamic and cyclic loading situations, typical in real-world applications and essential in understanding long-term dependability and fatigue resistance, has not been studied. The impacts of temperature changes on material qualities and hydraulic fluid performance are not considered, leaving the machine's efficiency during lengthy operations or in different climatic circumstances unknown. Sustainable and cost-effective operations require energy efficiency and recovery mechanisms, which the paper ignores. Contemporary safety elements, including pressure relief valves, interlocks, emergency stop systems, and operator ergonomics, are also ignored despite their importance for safe and easy operation. In addition, the study lacks actual prototyping and testing to verify design predictions and find differences between simulations and real-world performance. Objective constraints like time, resources, and advanced testing facilities may explain these disparities. Modeling dynamic forces, fatigue life, and thermal effects is computationally demanding and requires specific tools and skills. Future studies in these undiscovered regions could lead to a more durable, efficient, and dependable hydraulic press design for industrial applications.

The paper [13] discusses how a hydraulic press plate can be optimized for design using Finite Element Analysis (FEA), a big deal for boosting structural performance, efficiency, and longevity. However, numerous key features of the topic remain unresolved limiting its application. Dynamic and cyclic loads, crucial to fatigue life and long-term reliability, have not been studied. The research also ignores temperature impacts, which might affect material characteristics and structural performance during continuous operation or in different environments. Plastic deformation, creep, and anisotropy, which are crucial under severe loads, are ignored in the study. The press plate, hydraulic system, and workpiece contact and interaction effects are not analyzed, leaving unexplored stress concentration and uneven load distribution. Optimal real-world performance requires experimental confirmation of simulation results, which is lacking. In addition, the study does not use multi-objective optimization to balance weight, cost, and durability. Limitations including time, finances, and advanced testing facilities, may explain these differences. These crucial components are also omitted due to computational and methodological limitations in simulating dynamic forces, nonlinear material behavior, and contact mechanics. Addressing these limits in future studies would improve industrial hydraulic press plate reliability, efficiency, and applicability.

According to the paper [14], using Finite Element Analysis (FEA) to study the mechanical properties and optimize hydraulic press components under slow-loading situations has improved our knowledge of safety, efficiency, and structural behavior. Several key areas are undiscovered, limiting the study's application to further operational scenarios. The study optimizes hydraulic press components but not their system interaction. Unexplored are load transfer, joint stresses, and component alignment. Assuming linear elasticity simplifies material behavior and ignores nonlinear features like plastic deformation and creep that are important under high stress or prolonged loading. The approach also ignores system-level interactions like load transmission and joint stresses, which might impair hydraulic press performance. Experimental validation is lacking, leaving simulation results untested in real life. The study also ignores energy efficiency and sustainability, which modern hydraulic press designs require. Limitations in resources and scope and methodological difficulties in modeling dynamic forces, nonlinear material behavior, and multi-physics simulations explain these gaps. Future research on hydraulic press performance and optimization should address these constraints using improved computational approaches, system-level analysis, and experimental testing.

In the paper [15], sustainable manufacturing solutions that are both cost-effective and robust have been developed through the optimization of a recycled aluminum pressing machine's design structure using Finite Element Method (FEM). Numerous essential parts of the topic remain unexplored, limiting its real-world application. The impact of temperature changes on material characteristics and machine performance is ignored. Real-world environmental effects like humidity, corrosion, and wear are ignored. The study does not address thermal and environmental impacts such as temperature variations, corrosion, and wear, which might affect material performance and machine durability. The analysis focuses on structural components and ignores the pressing plate, frame, and hydraulic system, which may affect stress distribution and operational efficiency. Energy efficiency and sustainability, crucial to modern manufacturing, are also absent, leaving the machine's energy consumption and recovery unknown. The work also lacks the experimental validation necessary to verify FEA results in real-world situations. Objective constraints, such as the study's scope and resources, and computational and methodological hurdles in simulating dynamic forces, thermal effects, and material variability may explain these discrepancies. Advances in simulations, system-level analysis, and experimental testing would help researchers understand the machine's performance and make it more reliable, efficient, and sustainable for industrial use.

The paper [16] stated that axially compressed cylinders are extensively utilized in mechanical systems, civil structures, aircraft, and other engineering fields because of their exceptional load-bearing capabilities. Due to several vital gaps, its real-world applicability is limited. Post-buckling cylinder behavior is crucial to understanding how structures behave after buckling, but the study does not cover it. Structures can shift burdens and retain some functionality, but this is unexplored. Nonlinear features like plastic deformation, anisotropy, and creep, which are crucial for modern materials like composites, are ignored in the study. Temperature changes, corrosion, and moisture, which can substantially alter material qualities and worsen flaws, are also ignored. The research does not examine scale impacts and complex shapes but focuses on simple cylinder geometries. Experiments are needed to verify numerical and theoretical predictions; therefore, the results would not be reliable without them. Objective restrictions, such as a focus on core components, and computational obstacles, such as modeling dynamic forces, nonlinear material behaviors, and multi-physics effects, explain these gaps. Testing limitations like complex facilities and high prototyping costs may have hindered experimental validation. Next-generation simulations, system-level analysis, and experimental testing would improve localization-induced buckling understanding, structural design, and safety.

The study [17] on the bending deformation properties of water-hydraulic high-pressure soft actuators has revealed considerable promise for underwater manipulators. Several crucial areas remain unknown, limiting the findings' application. Static or steady-state pressure conditions are studied, ignoring dynamic or transient forces such as undersea currents, fast load changes, and vibrations. In addition, it does not test actuator material fatigue under repeated loads, which is essential for determining real-world durability and reliability. Performance under high pressures is affected by viscoelasticity, plastic deformation, and material creep, which are ignored in the research. The study also ignores environmental issues, including temperature, salinity, and biofouling, which can change material characteristics and hydraulic efficiency. Even though underwater manipulators need real-time control systems and sensors to monitor pressure, deformation, and positioning, they are not integrated. Experimental validation is needed to validate simulation accuracy under actual underwater settings however the paper lacks it. The small study focus and computational problems of modeling dynamic pressures, nonlinear material behaviors, and environmental influences require significant resources and expertise, which may explain these gaps. Test restrictions, including the lack of underwater labs, add to the exclusions. Advanced simulations, experimental testing, and system-level analysis would help improve the actuator's performance and underwater design.

Research [18] shows that double-acting, double-end hydraulic cylinders for industrial automation have improved in structural integrity, material efficiency, and dynamic performance thanks to design and finite element analysis. The research successfully handles stress distribution and material selection, but some crucial elements remain unresolved, restricting its applicability. The study analyzes the hydraulic cylinder without considering its interaction with mounting frames, hoses, and actuators within the automation system. Misalignment, unequal load distribution, and wear can result from these interactions. This research does not examine how the hydraulic cylinder interacts with other automation system components, such as mounting frames, hoses, and actuators, which could cause misalignment and unequal stress distribution. Seal performance, which prevents leaks and maintains efficiency at high pressure, is ignored. Automation applications require control and feedback systems for precision and adaptability, which are missing. Also, the study lacks experimental validation, leaving FEA results untested in real life. Due to the study's constrained aim, limited resources, and time constraints, these omissions occurred. Methodological issues, including modeling dynamic forces, nonlinear material behavior, and multi-physics effects, leave areas untouched. Future studies using improved computational approaches, system-level analysis, and actual testing would improve hydraulic cylinder designs for industrial automation reliability, efficiency, and practicality.

All this allows us to argue that it is appropriate to conduct a study devoted to developing a portable hydraulic press machine that is robust enough to endure the mechanical loads experienced in real-world applications without compromising efficiency or structural integrity. One of the most significant design factors is ensuring the press is lightweight and durable enough to resist high-force activities. For the hydraulic system to achieve its objectives, it must effectively apply loads while minimizing the amount of energy lost.

3. The aim and objectives of the study

The study aim is the development of a mobile hydraulic press machine. This will allow the press to meet the field-based application's structural and operational requirements and set a new standard for performance, durability, and flexibility.

To achieve this aim, the following objectives are accomplished:

– to simulate the load conditions and evaluate stress distribution;

– to simulate the load conditions and evaluate total deformation;

– to simulate the load conditions and evaluate safety factors.

4. Materials and methods

4. 1. Object and hypothesis of the study

The object of the study is the double-acting, double-ends hydraulic cylinder used in industrial automation applications. Critical components such as the cylinder body, piston rod, and sealing systems are examined in the study because of their importance to the mechanical design. This study examines the distribution of stresses, patterns of deformation, and safety considerations under different operating situations using Finite Element Analysis (FEA). The goal is to achieve optimal performance of the cylinder regarding longevity, efficiency, and adaptability in automation duties. This means dealing with issues including misalignment, dynamic loads, and material selection for industrial settings.

The main hypothesis of the research is that a double-acting, double-ends hydraulic cylinder can be substantially improved in terms of durability, efficiency, and adaptability for use in industrial automation by optimizing its design and evaluating its performance using Finite Element Analysis (FEA). The study proposes that the cylinder can obtain better dependability and a longer operational lifespan by locating and fixing stress concentration locations, deformation patterns, and material restrictions. The performance under real-world settings is projected to significantly improve by including solutions for dynamic loading, thermal effects, and misalignment. Theoretically, typical problems like wear and leakage can be reduced using cutting-edge sealing technologies and high-tech materials. In general, the hypothesis is based on the assumption that the upgraded design will be able to handle the demanding requirements of contemporary industrial automation systems.

This research assumes that the high-strength steel or alloys utilized to construct the hydraulic cylinder's two ends are homogeneous and have the same mechanical performance regardless of the applied load. Axial loads and internal pressures are supposed to be uniformly distributed, and there are minimum external disturbances, such as misalignment or side forces, under which the hydraulic cylinder is believed to function. Rather than considering dynamic or impact pressures, the loading circumstances are mainly seen as static or quasi-static, emphasizing steady-state operational scenarios. In addition, it is presumed that the production quality is perfect, devoid of any defects that could affect the stress distribution or overall performance, such as dimensional mistakes or welding flaws. Environmental problems such as high temperatures, corrosion, and fluid contamination are deemed insignificant or within controllable bounds to keep the emphasis on the cylinder's structural and operational features.

This study has implemented various simplifications to enhance the analysis and concentrate on the primary objectives. The materials in the hydraulic cylinder are considered uniform and consistent, guaranteeing a predictable mechanical response and disregarding any potential variations or flaws. Boundary conditions are defined in an idealized manner, incorporating evenly distributed axial loads and internal pressures while deliberately omitting side loads, misalignments, or uneven load distributions. The examination focuses solely on static and quasi-static loading conditions, thereby streamlining the consideration of dynamic or impact forces. Furthermore, it is presumed that the hydraulic cylinder is produced without any flaws and is devoid of defects like dimensional inaccuracies or welding inconsistencies that might impact its performance. Environmental factors such as temperature fluctuations, corrosion, and fluid contamination are overlooked in favor of focusing on the structural and operational performance of the cylinder under controlled conditions.

4. 2. Methods of the research

Design-Based Research (DBR) is a systematic technique that identifies problems, designs solutions iteratively, and then evaluates those solutions to create practical and successful solutions. This research uses this methodology [15, 19]. Before diving into the DBR process, it's important to do a thorough problem analysis to identify the current hydraulic press machines' limitations and the unique needs for efficiency, portability, and durability. A comprehensive literature review following this analysis examines previous research on material selection strategies and mobile hydraulic press machines. Insights from the literature inform the concepts of design and materials selected for the new machine. A comprehensive model of the mobile hydraulic press machine is created during the design process using Computer-Aided Design (CAD) software. By precisely visualizing and refining the design with CAD software, we can ensure that all parts align with the project's structural and functional objectives. Here, we pay close attention to material selection, which entails checking important qualities including ductility, stiffness, elasticity, and strength [20]. The components' ability to resist operational loads without breaking or deforming too much depends on these qualities.

After the first design is finished, the model is examined with the help of ANSYS, a robust FEA program. The FEA method replicates the actual operating circumstances by subjecting the CAD model to loads and boundary conditions. This analysis helps find areas of high stress, patterns of deformation, and other performance problems that could affect the machine's operation or safety. The research may evaluate the design's resilience and dependability using ANSYS, which allows them to forecast the machine's behavior under different load scenarios. The study would not be complete without determining the safety factor, a metric for gauging the machine's robustness and security. When calculating the safety factor, divide the applied load by the material's maximum load-bearing capability. The research considers safety during analysis to ensure the design is safe for real-world scenarios. Minimizing material usage and total dimensions contributes to a more efficient and cost-effective design while guaranteeing that the equipment meets safety regulations.

The DBR technique is iterative thus, the design can be fine-tuned continuously according to the simulation findings. If the analysis finds places with a lot of stress or deformation, we change the design to fix those spots and then retest it. The result is a safe, effective, and optimized product for the field because of this iterative design, analysis, and improvement process. A mobile hydraulic press machine that can handle the challenges of today's farms and factories is created in this study by combining the DBR approach with state-of-the-art CAD and FEA methods.

4. 3. Model of the mobile hydraulic press machine

The mobile hydraulic press machine is engineered with significant dimensions to facilitate various pressing operations while ensuring portability for field use. The dimensions are 4,350 mm in length, 1,700 mm in width, and 2,600 mm in height. These proportions offer a robust foundation and sufficient workspace, guaranteeing that the machine can accommodate huge materials and components without jeopardizing safety or productivity. This press machine features two hydraulic telescopic cylinders, each fulfilling an essential role. Table 1 below delineates the comprehensive characteristics of the mobile hydraulic press machine, elucidating its technical capabilities and design attributes.

Fig. 1 shows the mobile hydraulic press machine's schematic, breaking down its parts and explaining what they do. Maximizing operational efficiency, user-friendliness, and mobility were the primary design goals. Its essential components are the press machine's main frame, hydraulic telescopic cylinders, garbage pressing door, folding ladder, garbage intake funnel, and digital scales.

The main frame is its structural backbone, which supports and stabilizes the machine during pressing operations. The frame's high-strength steel (ASTM A36) construction allows it to withstand heavy loads and strains of the hydraulic system. Other essential parts are also housed in the frame, guaranteeing they are properly fastened and positioned for maximum efficiency. Two separate hydraulic telescopic cylinders are part of the apparatus, each with its duties. An essential component for both security and functionality is the pushing door. It safeguards the operator by enclosing the pressing chamber and stopping material spills during operation. Even when loaded with large objects, the door's hydraulic mechanism provides precise control and effortless opening and closing.

Table 1

Specifications of the mobile hydraulic press machine

No.	Specification	Details
1	Material properties	Steel plate ASTM A36
2	Overall dimensions	4,350 mm (L)×1700 mm (W)×2,600 mm (H)
3	Hydraulic system pressure	9.80665 MPa
4	Primary cylinder stroke length	750 mm
5	Secondary cylinder stroke length	707 mm
6	Power source	Electric motor
7	Control system	Automated hydraulic controls
8	Safety features	Emergency stop, pressure relief valves

The machine's top components, including the trash inlet funnel, can be accessed using the transportable ladder. To further reduce the machine's environmental impact and enhance mobility, the ladder may be folded when not in use, contributing to its compact design. Durable and lightweight materials were used to build the ladder, making it easy to use and protect the operator. The entrance funnel guides materials into the pressing chamber, creating the ideal conditions for efficient compression. Due to its thoughtful design, it allows materials to enter the machine with little disruption and maximum efficiency. Built to endure the rigors of constant material loading, the funnel is tear-resistant.

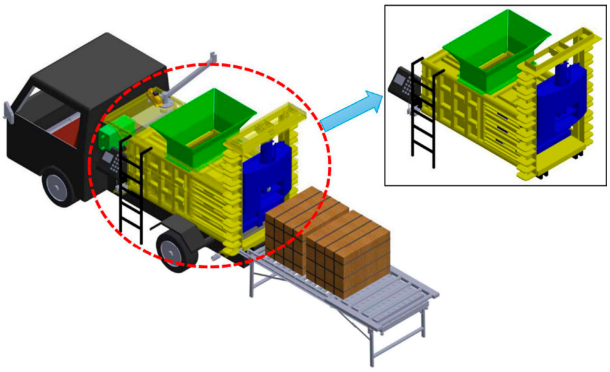


Fig. 1. Mobile hydraulic press machine design

4. 4. Mesh convergent

A complex structural system can be computationally analyzed using the Finite Element Method (FEM), which splits it into simpler elements. Enumeration or meshing is essential for accurately simulating the system's physical properties. Through finite elements, FEM can evaluate quantities like stress, strain, and deformation that would be difficult or impossible analytically. Due to their advantages, hexahedron and tetrahedron elements (automated method) were meshing elements for this investigation. Simulation accuracy and efficiency are best with hexahedral elements for simple geometries. Due to their regular design, nodes and elements are evenly distributed, resulting in more accurate outputs with less computational power. In areas with a non-uniform structure, tetrahedral elements are versatile and can mesh complex or irregular shapes. They work well together to integrate simple and complex design elements accurately.

The mesh results for various essential mobile hydraulic press machine components are shown in Fig. 2. Finite Element Analysis (FEA) produced these mesh results to mimic machine behavior under different loading circumstances. The mesh findings show how elements are distributed across the model and help determine stress concentrations, deformation, and other machine performance metrics. Fig. 2, *a* shows the findings of the hydraulic telescopic cylinder mesh. This analysis balances computational efficiency and accuracy with 50 mm elements. The mesh represents material distribution and hydraulic cylinder reaction under stresses with 13,075 nodes and 6,379 elements. This smaller mesh adequately captures the essential areas around the cylinder's piston and seals, providing thorough stress and deformation analysis during pressing. This mesh shows the hydraulic cylinder's structural performance and failure points, which are crucial components.

The press machine frame mesh is depicted in Fig. 2, *b*. The machine's stability and load-bearing capabilities depend on this part. The mesh has 350,588 nodes and 97,805 elements, indicating a comprehensive simulation. A thick mesh is needed to capture the intricate interactions between frame elements under load. The frame must survive significant pressures and deformation, thus this analysis checks every part for durability and structural integrity. This mesh identifies weak points needing reinforcement or alteration for safe pressing.

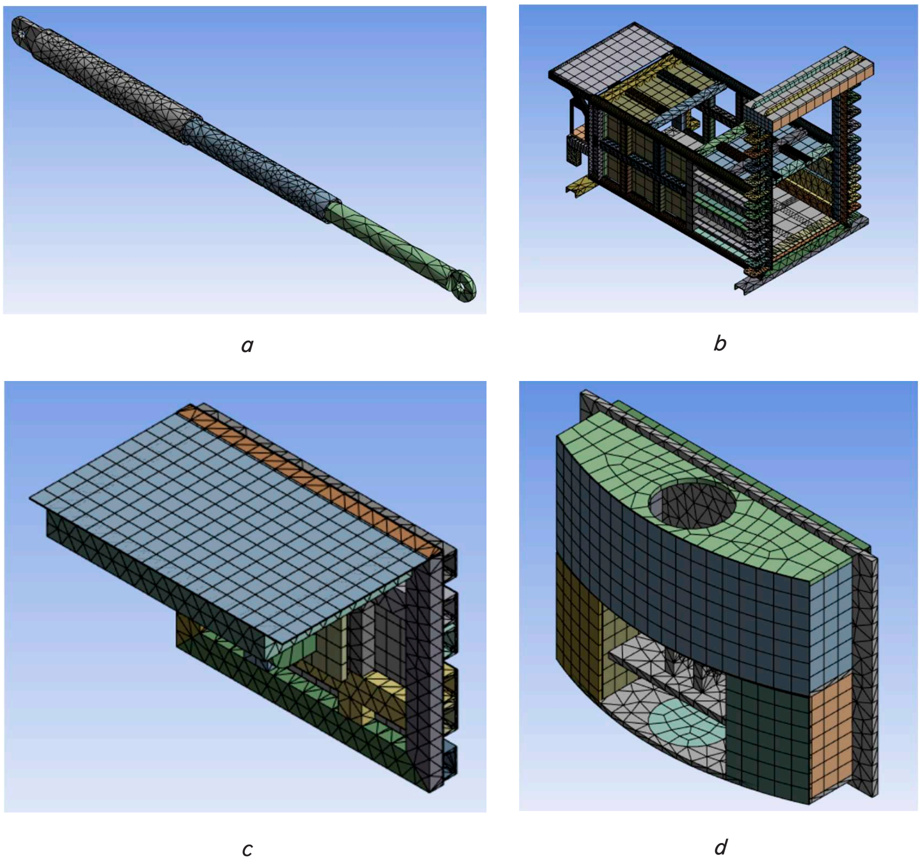


Fig. 2. Mesh geometry of: *a* – hydraulic telescopic cylinder; *b* – press machine frame; *c* – waste press; *d* – waste press door

Waste press mesh findings are presented in Fig. 2, *c*. The machine's compression and waste material processing section is under high mechanical stress. This section's mesh tracks waste press deformation and stress with 29,816 nodes and 12,480 components. To operate the hydraulic press, the waste press section must endure waste compression pressures. This mesh analysis ensures that it can. Optimization of material consumption and structural strengthening is possible. The waste press door part, which controls material flow into the press, is meshed in Fig. 2, *d*. The hydraulically operated door must open and close smoothly and satisfy operational and safety concerns. The component mesh has 28,306 nodes and 9,404 elements. This comprehensive research helps discover stress concentrations around door hinges and hydraulic cylinders, essential for door reliability. The mesh results also reveal the door's deformation during operation, helping to prevent excessive bending or twisting that could hamper movement or cause failure.

4. 5. Boundary conditions

The simulation boundary conditions for each mobile hydraulic press machine component are shown in Fig. 3. These boundary conditions must appropriately represent physical limits and forces experienced by the machine during operation. Realistic loads and supports ensure that each component's stress, deformation, and other performance indicators are tested under real-world conditions. A fixed support anchors the hydraulic telescopic cylinder (Fig. 3, *a*) base at point A to prevent translational or rotational movement. This fixed support physically connects the cylinder and machine frame. Two 245,166 N (25-ton) forces act at B and C. These forces imitate hydraulic pressure during operation, including telescopic cylinder internal pressure and piston external forces. Structural integrity and stress distribution along the cylinder are assessed using this configuration.

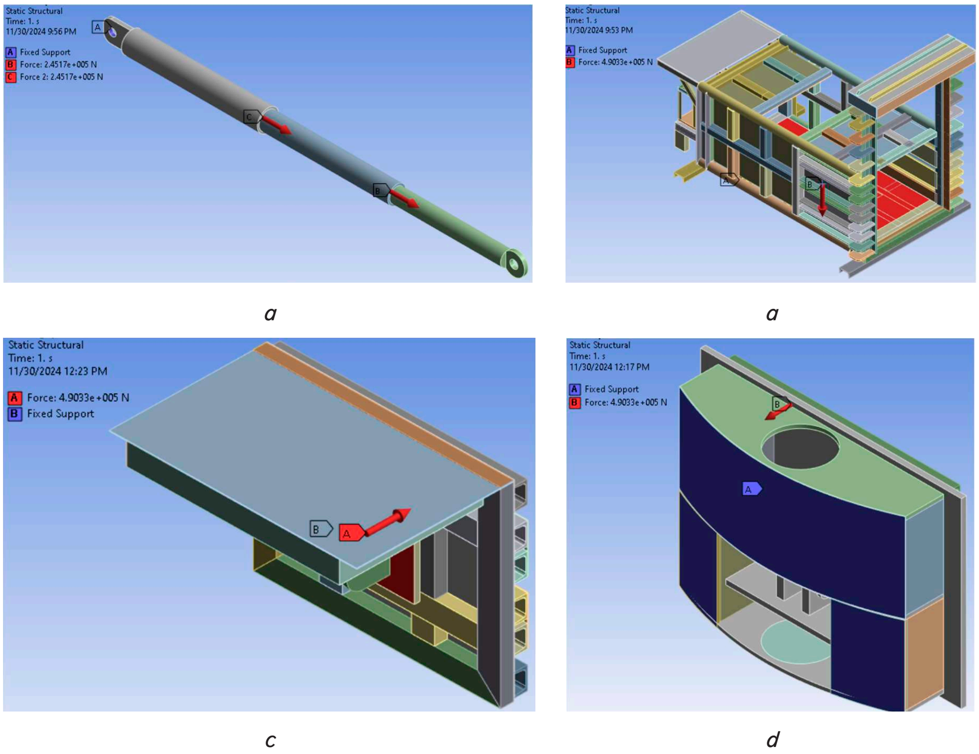


Fig. 3. Boundary conditions of: *a* – hydraulic telescopic cylinder; *b* – press machine frame; *c* – waste press; *d* – waste press door

Fixed support is at point A, where the press machine frame (Fig. 3, *b*) is securely bolted or welded to the base. This keeps the frame still under load. Point B simulates the hydraulic telescopic cylinder load during pressing with a 490,333 N (50-ton) downward force. The frame's ability to endure hydraulic system loads and material weight depends on this boundary condition. The study also reveals frame locations that may need reinforcing to prevent deformation or failure. Waste press section boundary constraints include permanent support at point A that secures it to the main frame. This fixed support stabilizes compression. At point B, 490,333 N (50-ton) simulates the hydraulic force used to squeeze waste items (Fig. 3, *c*). This setup evaluates stress distribution and deformation in the waste press section to ensure it can crush various materials. Fixed support at point A represents the hinge or pivot points securing the press frame's waste press door. At B, 490,333 N (50-ton) simulates the hydraulic force to open and close the door (Fig. 3, *d*). This boundary condition is crucial for assessing the door's structural performance, especially at the hinges and force points. The analysis assures the door operates smoothly without deformation or wear, even after multiple loading cycles.

4. 6. Material properties

This mobile hydraulic press machine's structure is constructed from Steel Plate ASTM A36, a structural steel grade extensively utilized due to its cost-effectiveness and outstanding mechanical qualities. Hydraulic press frames necessitate a sturdy build, and this material is perfect for that job because of its availability, high yield strength, and excellent machinability. The ultimate tensile strength of ASTM A36 Steel Plate can be anywhere from 400 to 550 MPa, and its yield strength is around 250 MPa, or 36,000 psi. Because of these mechanical characteristics, the frame will not permanently deform or fail under the enormous strains and loads experienced during pressing operations. In addition, the material's high ductility improves the machine's resilience to field-applied shocks and impacts by absorbing energy under dynamic loading circumstances.

Mechanical strength isn't the only thing that makes ASTM A36 steel great; it's also quite easy to weld and machine. These features make accurate cutting, shaping, and joining of the frame components possible, which eases the fabrication process. Fabrication is a breeze, so you can ensure the frame is exactly how you want it while the joints and load-bearing regions stay strong. Welding processes guarantee solid, smooth component connections, which increases the frame's reliability and longevity. Even though it isn't as good as specially designed corrosion-resistant alloys, ASTM A36 steel has more than enough resistance to corrosion for most uses in the field. The frame can be protected from moisture and hard circumstances by applying additional surface treatments like galvanization, powder coating, or painting. This will increase its service life. The design balances strength, durability, and cost-efficiency by using Steel Plate ASTM A36. Using this material on the frame decreases production costs while providing the structural support the hydraulic press needs. An integral part of the mobile hydraulic press's construction, ASTM A36 is known for its dependability and versatility, which allows the equipment to work well in various field applications.

4. 7. Mathematical model

This study assesses a mobile hydraulic press machine's structural and operational performance by examining three important mathematical models. When testing a machine's reliability and safety in real-world settings, it is crucial to use these models: Equivalent Stress, Total Deformation, and Safety Factors. You can learn something new about the machine's performance from each model. At each given location in the structure, the stress state can be measured by calculating the equivalent stress using the von Mises criterion. A single scalar value indicates the stress intensity after considering the combined effect of normal and shear stresses. This model is very helpful in determining if any component of the machine is at risk of failure or plastic deformation due to material exceeding its yield strength. Redistributing loads and reducing stress concentrations can be achieved by refining the design in response to regions of high equivalent stress.

When subjected to applied loads, total deformation denotes the cumulative displacement of a machine's components. This model assesses the displacement of the frame, hydraulic cylinder, and other essential components of the machine from their initial positions when exposed to operational stresses. The research analyzes overall deformation to ensure displacements remain within acceptable limits, preventing misalignment, diminished efficiency, or damage to the hydraulic press. It also assists in validating the design's rigidity, especially in field operations where stability is essential. The safety factor is a dimensionless metric employed to assess the structural integrity of the machine under peak stress circumstances. The calculation is based on the material's yield strength ratio to the equivalent stress endured by the structure. A safety factor exceeding 1 signifies that the design is secure, with elevated values offering increased safety margins. This model guarantees that the machine is structurally robust and capable of withstanding unforeseen loads or functioning in adverse conditions without the risk of failure. The study thoroughly assesses the machine's performance by analyzing mathematical models via Finite Element Analysis (FEA). The insights derived from these models inform design enhancements, including the reinforcement of high-stress regions, the optimization of material utilization, and the assurance that all components comply with safety and operating standards. Collectively, these models establish the basis for creating a durable, efficient, and dependable mobile hydraulic press machine.

5. Results of the design and simulation of the mobile hydraulic press machine

5. 1. Results of the stress distribution of the mobile hydraulic press machine

The structural integrity of crucial components under operational loads was evaluated by conducting a stress distribution analysis of the mobile hydraulic press machine using Finite Element Analysis (FEA). The findings shed light on the most stressed regions, which aids in pinpointing possible weak spots and confirming the machine's reliability and efficiency. Fig. 4 shows the findings of the equivalent stress distribution (von Mises stress) for several parts of the portable hydraulic press. The machine's performance and structural integrity were assessed under operational settings using Finite Element Analysis (FEA), which yielded these results. The hydraulic telescopic cylinder with a maximum stress of 599.51 MPa is shown in Fig. 4, *a*. Due to internal pressure and external forces occurring during the pressing action, it undergoes its maximum stress near the connection points and along the cylinder walls. The stress progressively reduces as the cylinder moves away from high-load areas. This pattern shows that the cylinder body is structurally resilient and that load transfer is effective. The maximum stress does not exceed the alloy steel's allowed yield strength, guaranteeing that the hydraulic cylinder may operate safely and without failure.

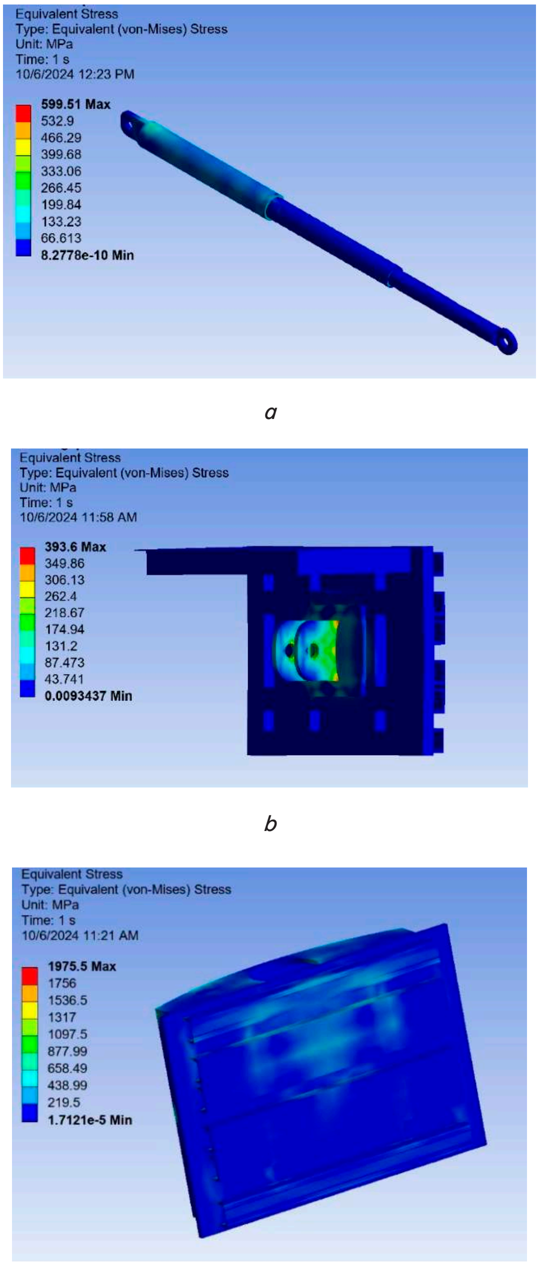


Fig. 4. Stress distribution of: *a* — hydraulic telescopic cylinder; *b* — waste press; *c* — waste press door

The press machine frame was shown with a maximum stress of 393.6 MPa in Fig. 4, *b*. Concentrations of stress on the press machine's frame are most noticeable when the hydraulic cylinder exerts force. This stress is concentrated near important joints and places of attachment. Less stress is present in places further from the hydraulic contact points as the stress radiates outward from the load application points. The stresses are evenly distributed throughout the frame, and the highest stress readings are below the ASTM A36 steel yield strength. This guarantees the structural stability of the frame under operational loads. The waste press door with a maximum stress of 1975.5 MPa is shown in Fig. 4, *c*. The hinge and areas close to the hydraulic force application points are the most stressed areas of the waste press door. The consistent decrease in stress from the force application locations indicates proper force dissipation across the door's surface. Even in certain places with severe stress, those spots can be reinforced to make the door last longer and keep it from deforming or weary. Operating safely under anticipated load situations is a primary goal of the design.

The stress levels found in the waste press door, waste press, and hydraulic telescopic cylinder-three crucial components of the mobile hydraulic press machine-are compared in Fig. 5. The graph's dashed line represents the ultimate tensile strength (UTS) of ASTM A36 steel, and these stress values are evaluated. Under real-world scenarios, the analysis helps gauge how each part holds up structurally and how much room there is for error. The waste press door has the highest stress value among the components, reaching around 120 MPa. There is probably a concentration of stress here because the door is subjected to much force as it opens and closes, especially at the hinge points and where the hydraulic force is applied. The observed stress is significantly lower than the UTS of ASTM A36 steel, suggesting a safe design with a large safety margin, even though it is the most stressed component. However, a redistribution of load or localized reinforcements could improve the component's endurance due to the relatively high stress level.

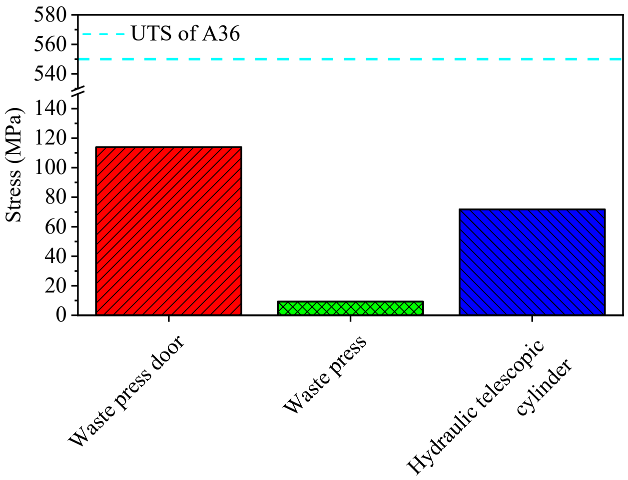


Fig. 5. Average stress distribution of the mobile hydraulic press machine

Compared to other sections, the waste press section has the lowest stress value, around 20 MPa. This low stress level indicates that the load has been distributed well, and there are few localized concentrations in this system component. The waste press section's structural robustness is evident from its capacity to bear its operational load with low stress. There is no immediate need to modify or reinforce the design. The hydraulic telescopic cylinder records a mild stress value of about 80 MPa; this value is also well within the material's safety limits. This stress is common for parts subjected to strong axial loads and high hydraulic pressure. The design of the cylinder efficiently controls the applied forces, allowing the material to remain within the elastic range while it is being operated. Under the anticipated operating conditions, its stress level verifies the hydraulic system's reliability. The figure's dotted line displays the Ultimate Tensile Strength (UTS) of ASTM A36 steel, around 550 MPa, and is used as a standard for determining the components' safety. There is no danger of material failure in the operational design because all stress levels are much below this threshold.

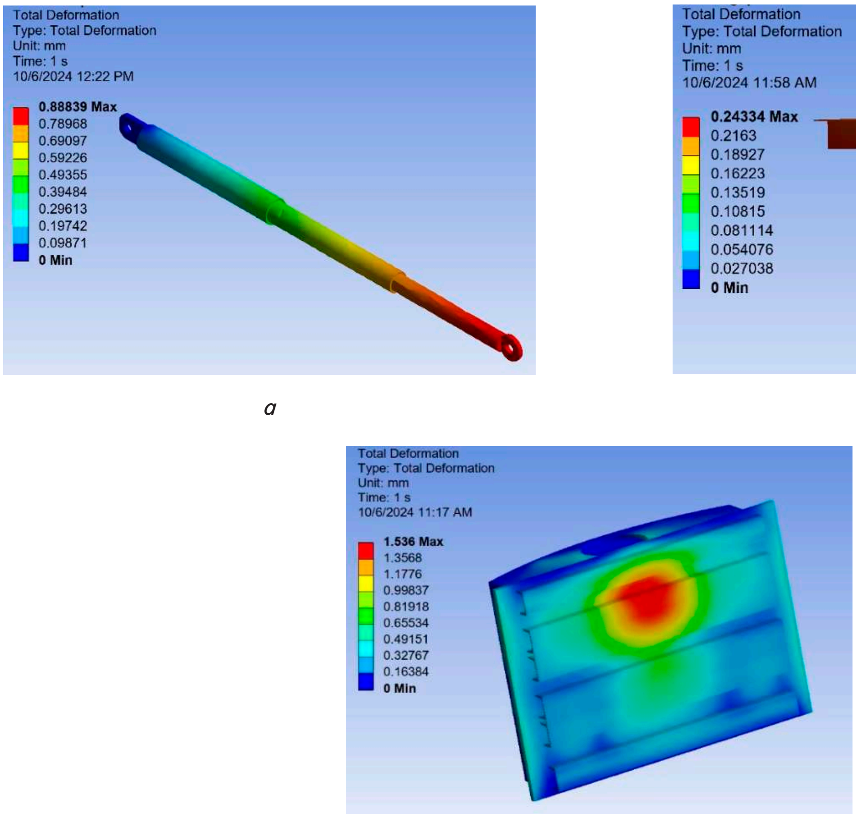
5. 2. Results of the total deformation of the mobile hydraulic press machine

The hydraulic telescopic cylinder, press machine frame, and waste press door are crucial components of the mobile hydraulic press machine. The results of the overall deformation analysis for these parts are shown in Fig. 6. These findings, derived from Finite Element Analysis (FEA), shed light on how each part deforms when subjected to loads, guaranteeing that the deformation stays within safe parameters for effective and secure functioning. The hydraulic telescopic cylinder with a maximum deformation of 0.8839 mm is shown in Fig. 6, *a*. At the end of the telescopic cylinder, away from the fixed support, axial and bending forces combine to cause the greatest deformation. An efficient load transfer along the structure is indicated by the distortion gradually decreasing as the cylinder approaches the fixed base.

The press machine frame exhibits a maximum deformation of 0.24334 mm, as shown in Fig. 6, *b*. Deformation is less noticeable in the press machine frame than in the other examined components. It is highest in the regions where the hydraulic cylinder applies direct force. The distribution of deformation is uniform over the frame, with localized peaks close to the places of load application. The negligible deformation under high compressive loads demonstrates the structural stiffness and stability of the frame. The waste press door with a maximum deformation of 1.536 mm is shown in Fig. 6, *c*. Out of all the parts, the waste press door shows the greatest overall deformation; the most extreme deformation is at the outside edge, which is the furthest from the hinge points. Because the door is securely fastened at the hinge region, the deformation diminishes in that direction, suggesting that the hinges effectively limit movement. This component has a higher degree of deformation but is still within acceptable operational limits, so the door can open and close and stay in the correct position.

Three essential parts of the hydraulic press machine – the waste press, the hydraulic telescopic cylinder, and the waste press door – show the average total deformation in Fig. 7. The comparison of results helps to understand the deformation of each component when subjected to operating stress. On average, the waste press door will deform by about 0.40 mm. The average deformation of the components is higher for the waste press door. The dynamic pressures applied during opening and closing, especially at the free edges furthest from the hinges, are the ones responsible for this, therefore it's not surprising.

The average total deformation of a waste press is about 0.20 mm. The minimal deformation observed in the waste press is a testament to this area's structural strength and efficient load distribution. Due to its efficient design and minimal deformation, the waste press needs no more modifications to perform well under operational loads. The hydraulic telescopic cylinder's average total deformation is about 0.38 mm. The hydraulic telescopic cylinder shows some modest deformation, mostly at the tip, due to axial forces and bending moments caused by the hydraulic pressure. The cylinder can work properly without misalignment or failure because the distortion is within the allowed range.



a

b

c

Fig. 6. Total deformation of: *a* – hydraulic telescopic cylinder; *b* – waste press; *c* – waste press door

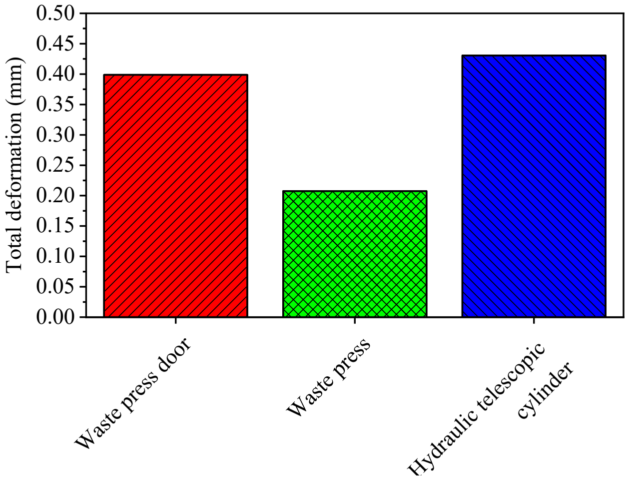


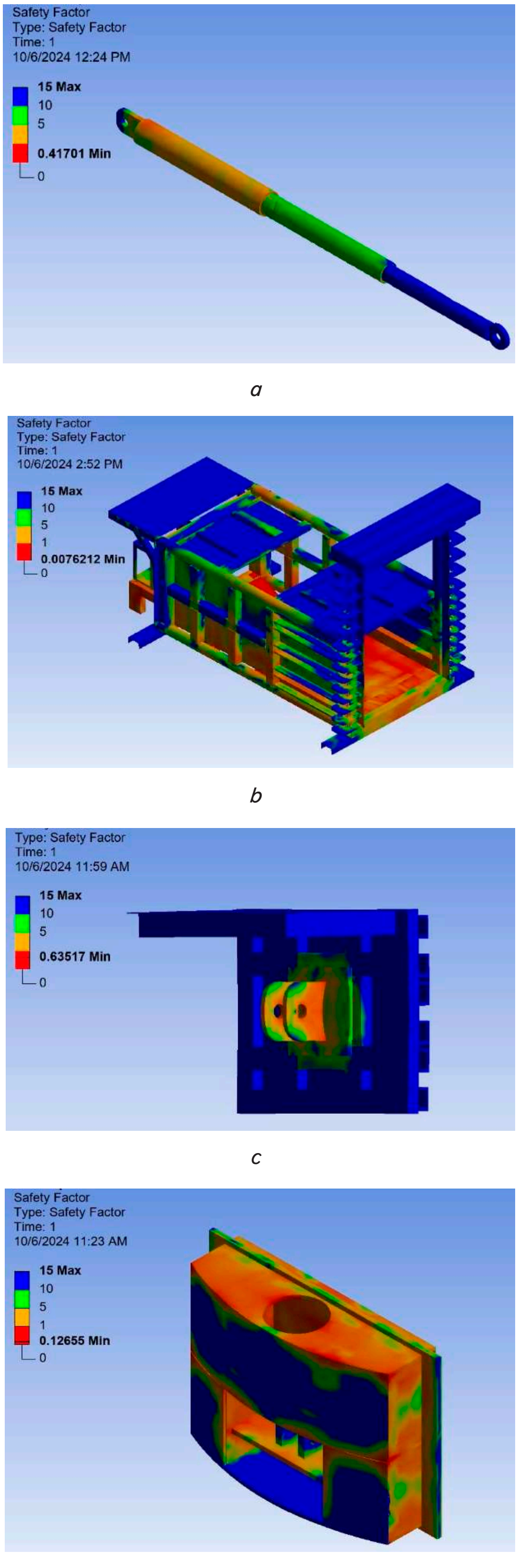
Fig. 7. Average total deformation of the mobile hydraulic press machine

5. 3. Results of the safety factor of the mobile hydraulic press machine

The mobile hydraulic press machine's critical components were subjected to a safety factor analysis, as shown in Fig. 8. The safety factor values determine each component's dependability and structural integrity under applied loads. The safety factor evaluates the buffer zone by contrasting the expected operational stress with the structural strength. Fig. 8, *a* shows the results of the hydraulic telescopic cylinder's safety factor study, which shows that the structural reliability is high, with most locations having a safety factor greater than 5. Nevertheless, 0.4171 is the lowest recorded number, and it happens close to the attachment point where the hydraulic stress is applied directly. There are noticeable structural changes in the safety factor of the press machine frame (Fig. 8, *b*). A high safety factor exceeding 10 in numerous places across the frame indicates that the structure is adequately overdesigned to withstand typical operational stresses. On the other hand, there are spots where the safety factor drops below 0.0076, usually in the load-bearing zones around the hydraulic cylinder connection points.

Fig. 8, *c* shows the waste press section, which has a safety factor between 0.6352 and 15. The safety factor is greater than 5 in most places, except for a few sites with lower values. These areas are usually located close to the press surfaces, which are subjected to hydraulic force when the machine operates. Fig. 8, *d* indicates that the waste press door has a safety factor range of 0.1266 to 15, with consistently high values throughout the structure. The safety factor drops the most when the door meets the hydraulic system's direct force and along its edge. While the safety factor does vary somewhat across parts, it is consistently high across the board, guaranteeing structural soundness. Low safety factors in certain places suggest that the hydraulic telescopic cylinder, press frame, and waste press door may need reinforcing.

Fig. 9 presents the average safety factor for four essential components of the mobile hydraulic press machine: the waste press door, the waste press, the hydraulic telescopic cylinder, and the press machine frame. The safety factor values offer a numerical assessment of each component's capacity to endure applied stresses about its material strength. The dashed line indicates the minimum acceptable safety factor, acting as a standard for assessing the design's reliability. The waste press door demonstrates a safety factor of around 4, suggesting it can manage the applied loads with an adequate margin of safety. Nevertheless, its diminished value relative to other components indicates a higher susceptibility to stress concentration and possible structural vulnerabilities.



a

b

c

d

Fig. 8. The safety factor of: *a* – hydraulic telescopic cylinder; *b* – press machine frame; *c* – waste press; *d* – waste press door

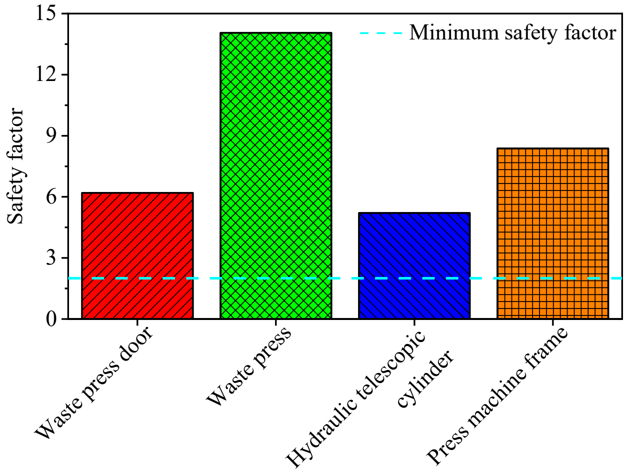


Fig. 9. Average safety factor of the mobile hydraulic press machine

Based on its sturdy construction and minimal stress levels under operating loads, the waste press exhibits the highest safety factor (around 13) among the components. This high safety margin guarantees outstanding reliability and long-term performance without additional adjustments. Appropriately for a heavy component, the hydraulic telescopic cylinder has the lowest average safety factor (around 3). It satisfies the minimally acceptable safety factor, but due to its vital function in the system, it needs close observation and maybe reinforcement in high-stress locations. Supportive under operating loads, the press machine frame has a respectable safety factor of around 5. However, its modest number implies that some localized stress sites close to the hydraulic cylinder attachment would require more care.

6. Discussion of the design and simulation of the mobile hydraulic press machine

The structural performance of the three important components of the mobile hydraulic press machine – the waste press door, the waste press section, and the hydraulic telescopic cylinder – can be better understood from the stress distribution analysis shown in Fig. 4, 5. The strength and dependability of the design in real-life situations are assessed by comparing the stress levels of these parts with the Ultimate Tensile Strength (UTS) of ASTM A36 steel, which is approximately 550 MPa. All components undergo different stress levels, but the waste press door reaches about 120 MPa, the most. This figure, albeit much lower than the UTS of ASTM A36 steel, indicates that it is the component under the greatest stress in the system. Hinge points and areas subjected to hydraulic force during opening and shutting cycles are the sources of the comparatively high stress level. Since these parts are mechanically important and subject to concentrated loads, they are likelier to experience elevated stress levels.

The waste press section shows the least tension, around 20 MPa. A well-designed system with efficient load distribution would have this figure substantially lower than the other components. With such a low stress level, it's clear that the waste press section's structure is strong enough to withstand the operational loads without localized stress. The even distribution of forces over this component guarantees minimal localized deformation and good structural reliability. Despite 80 MPa, the hydraulic telescopic cylinder registers a minor stress value – far lower than the material's UTS. Components exposed to high hydraulic pressure and significant axial stresses, as is common in hydraulic systems, sometimes experience this stress. The telescopic cylinder controls these forces well, so the material doesn't go beyond its elastic range when it acts. One way to decrease the likelihood of localized failure is by observing the progressive shift of stress down the length of the cylinder [16]. This indicates that the load is being evenly distributed.

The examination of average total deformation for the waste press door, waste press, and hydraulic telescopic cylinder (Fig. 6, 7) underscores the structural performance of these critical components under operating stress. The waste press door demonstrates the greatest average overall deformation at 0.40 mm. The increased deformation is predominantly concentrated at the free edges furthest from the hinges, where dynamic forces are most pronounced during the opening and shutting cycles. The deformation behavior of the waste press door is anticipated due to its ability to resist hydraulic forces during operation. The operational dynamic pressures, especially around the door edges, generate bending moments that lead to localized deformation. Although it is the most deformed component, the deformation stays within the material's elastic limits, preserving the door's functionality without irreversible distortion. Research on door-like structures subjected to hydraulic actuation highlights the necessity of reinforcing high-stress areas to reduce deformation and prolong durability [17].

The average overall distortion in the waste press is around 0.20 mm, the lowest. The minimal deformation demonstrates its structural robustness and efficient load distribution. During operation, the waste press experiences compressive forces that cause uniform deformation throughout its structure. There are no major stress concentrations or weak spots in the waste press, as shown by the low deformation value. This proves that its design is sufficient for keeping alignment and structural integrity intact over time. According to studies conducted on compression structures, evenly distributed stress helps to limit deformation and the requirement for further reinforcement [21]. Because of axial stresses and bending moments caused by hydraulic pressure, the hydraulic telescopic cylinder shows a moderate average deformation of about 0.38 mm, with most of the deformation centered at the cylinder tip. Under the extreme hydraulic pressure, the telescopic cylinder distorts as it moves. The progressive distortion shift from its base to its tip shows its effective load transfer along its length. Ensuring the cylinder remains properly aligned and functional without risk of failure, the distortion stays within allowed limits. According to research on hydraulic systems, controlling the prevalent phenomenon of free-end deformation in hydraulic cylinders is possible by making optimum design and material selection decisions [18].

The press machine frame, hydraulic telescopic cylinder, waste press, and waste press door are the four main parts of the mobile hydraulic press machine, and their average safety factors are shown in Fig. 8, 9. One important way to measure a component's structural integrity and reliability is by looking at its safety factor. This metric compares data to the minimum allowable safety factor, which the dashed line indicates. A modest safety factor suggests that the waste press door can bear the applied stresses with a sufficient margin of safety. Under dynamic hydraulic loading, however, the door's reduced safety factor makes it more susceptible to stress concentrations at crucial points like hinges and edges. Frustration or failure may result from this increased vulnerability to stress concentrations if not addressed. Researchers [17, 22, 23] found that door-like structures should be reinforced around hinges to make them more resistant to dynamic forces and reduce deformation when subjected to repeated loading.

The waste press portion has the highest safety factor because of its structural strength and low operational stress. The component's safety factor of 13 implies that it is over-designed and can withstand applied stresses. This high safety factor indicates that the waste press will function reliably and last without modifications or enhancements. The waste presses with a greater safety factor have longer lifespans and better structural performance under normal working conditions [24]. The hydraulic telescoping cylinder has the lowest average safety factor, around 3, although it fulfills the requirement. This lower result is expected, given the cylinder's high hydraulic pressure and axial forces. Since the cylinder generates the force needed for pressing, its safety factor, albeit adequate, should be monitored to prevent failure or misalignment, especially at attachment places where forces are concentrated. Due to their important function and high pressure, frequent inspections and structural reinforcements are recommended to keep hydraulic cylinders within the elastic range of material deformation [25, 26]. The press machine frame has a moderate safety margin with a safety factor of 5. Therefore, the frame can handle operational loads while being structurally stable. Its weak safety factor suggests localized stress concentrations, especially at hydraulic cylinder attachment sites. Localized reinforcing at stress concentration zones like cylinder attachments to increase press system structural stability and safety margin [27].

Although this study used a thorough design, modeling, and simulation approach, several limitations could still impact how the results are applied in real-world scenarios. This study's Finite Element Analysis (FEA) relies on material properties that have been simplified and idealized. Such assumptions as the materials' isotropy and homogeneity may not reflect their actual behavior in the real world, particularly when subjected to severe loads or other environmental factors. Research focuses on steady-state situations with static loading, where stresses and pressures are applied. Dynamic stress, such as cyclic loads, vibrations, and abrupt shocks, is common in real-world operations and may cause fatigue-related failures not considered in this study. Because they are based on theoretical qualities, optimizing the design and material selection processes could overlook practical manufacturing limitations like material availability, machining tolerances, or welding quality. The engineered and manufactured machines may end up being different as a result of this.

Several critical directions should be investigated to develop this study further. The long-term reliability of the hydraulic cylinder in industrial automation applications will be guaranteed by incorporating dynamic and fatigue analysis, which will provide a more comprehensive idea of its behavior under cyclic and impact forces. Incorporating advanced material modeling to account for nonlinear properties, such as plastic deformation and anisotropy, is important. Additionally, composite materials or high-strength alloys should be investigated to improve durability and reduce weight. By broadening the scope of the investigation to encompass environmental and thermal factors, including fluid contamination, corrosion, and temperature fluctuations, the cylinder's capabilities will be guaranteed in various challenging environments. System-level analysis should assess the hydraulic cylinder's interactions with other components in the automation system, enhancing overall performance and compatibility. Furthermore, integrating real-time monitoring systems with sensors and feedback mechanisms will enable the creation of smart cylinders capable of adapting to changing conditions with greater precision and safety. In conclusion, the design will be refined, and the simulation results will be validated through prototyping and experimental testing under realistic conditions. The hydraulic system's energy efficiency will also be enhanced to address sustainability and operational cost concerns. As a result of these advancements, hydraulic cylinder designs will become more advanced, reliable, and robust.

7. Conclusions

1. The waste press door, waste press, and hydraulic telescopic cylinder stress analysis shows that the mobile hydraulic press machine is structurally reliable and safe within ASTM A36 steel standards. All component stress levels are well below the Ultimate Tensile Strength (UTS) of 550 MPa, ensuring a large safety buffer under expected operational conditions. Due to hinge point and hydraulic force application stress concentrations, the waste press door has the highest stress, 120 MPa. The stress level is safe however the larger concentration highlights locations for strengthening or load redistribution to improve the door's longevity and performance. The waste press section has the lowest stress, 20 MPa, indicating excellent load distribution and structural robustness. It performs without modification and has little stress, indicating great reliability under operational pressures. The hydraulic telescopic cylinder has a mild stress of 80 MPa, typical for axially loaded components at high hydraulic pressure. The cylinder's design keeps the material elastic, ensuring reliability and safety.

2. The total deformation study highlights the structural performance of the waste press, hydraulic telescopic cylinder, and waste press door under operational loads. Waste press doors deform the most, averaging 0.40 mm. The dynamic stresses during opening and shutting cycles are the main culprit. The waste press displays a sturdy structure and good load distribution with an average deformation of 0.20 mm. Axial stresses and bending moments induced by hydraulic pressure distort the hydraulic telescopic cylinder by 0.38 mm, most visible near the tip. The machine is safe and reliable because all components' deformation values are within operational limits. The waste press door could use targeted reinforcements, but the hydraulic telescopic cylinder and waste press are structurally sound. These findings demonstrate the design can survive operational loads and suggest further enhancements.

3. The mobile hydraulic press machine's structural reliability is revealed by safety factor analysis of the waste press door, waste press, hydraulic telescopic cylinder, and press machine frame. A safety factor of 4 gives the waste press door enough tolerance for applied loads. Waste presses have the greatest safety factor, about 13, indicating reliability and structural strength. With a safety factor of about 3, the hydraulic telescopic cylinder surpasses minimal safety standards. This press machine frame has a safety factor of about 5, suggesting it can bear operational loads. The analysis's safe component operation confirms the mobile hydraulic press machine's structural reliability and functionality. The machine's efficiency, durability, and cost-effectiveness could be improved by targeted

strengthening in low-safety components (waste press door and hydraulic telescopic cylinder) and material optimization in overdesigned portions (waste press).

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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The study was performed without financial support.

Data availability

Data will be made available at a reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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