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Hydraulic Chip Compactor

Rahim, Nur Aien[1*], Hasan, Norhayati Abu[1], & Suhut, Fartini Mohd[1]

[1] Welding Technology Program, Sungai Buloh Vocational College, Sungai Buloh, Shah Alam, MALAYSIA

*Corresponding author email: m-6207597@moe-dl.edu.my

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Abstract: Effective management of metal waste is essential to ensure cleanliness, safety, and sustainability in machining workshop operations**.** This study presents the development of a small-scale hydraulic chip compactor, specifically designed to address waste management needs in the Welding Technology Workshop of Sungai Buloh Vocational College (KVSB). A practice-based design methodology was employed, encompassing technical drawing production, material selection, fabrication, performance testing, and user feedback assessment. The results indicate that the machine is capable of producing compact, uniform, and safely handled chip blocks, thereby optimizing space utilization and minimizing injury risks. Visual inspection and liquid penetrant testing confirmed that the welding quality met AWS and ASME standards without critical defects. Additionally, user feedback affirmed the machine's user-friendliness and effectiveness in vocational training environments. This research not only demonstrates the successful development of a functional hydraulic chip compactor but also highlights its potential as an innovative tool for integrating compaction technology into technical education systems.

Keywords: Chip Compactor, Welding Technology, Vocational Education

1. Introduction

Waste management in the metal machining and fabrication industry plays a vital role in ensuring operational efficiency and environmental sustainability. One of the primary by-products of machining processes—such as turning, cutting, and shaping—is metal chips, which are fragments or strips produced through material removal. The absence of a systematic chip management system can lead to an unclean, unsafe, and inefficient working environment (Gonzalez-Martinez et al., 2024). In this context, the chip compactor—particularly the hydraulic type—emerges as a technological innovation that compresses waste into denser forms, thereby facilitating storage, handling, and recycling.

A chip compactor, also known as a metal chip briquette or compaction press, is designed to transform loose metal chips into smaller, denser blocks or briquettes. This technology significantly reduces the space required for storage and transportation of metal waste, resulting in cleaner, more organized, and safer workplaces. Such systems typically comprise a hydraulic cylinder that generates high compressive force, a compression chamber engineered to withstand pressure, and a control system to regulate operations and monitor pressure levels (Zhou et al., 2021). From both economic and environmental perspectives, these machines can reduce waste disposal costs and support more sustainable recycling practices (Gupta et al., 2019).

However, preliminary observations at the Welding Technology Workshop of Sungai Buloh Vocational College revealed the absence of a chip compactor, despite the high volume of metal waste generated. Chips resulting from pipe turning and cutting processes frequently occupy excessive space in waste bins, leading to rapid overfilling, workplace clutter, and safety hazards. The uncompacted nature of these chips complicates waste handling and often causes injuries to students and staff due to their sharp, irregular forms.

A study by (Simon et al., 2017) demonstrated that chip compactors have the potential to reduce the volume of metal waste by up to 80%, while also saving space and simplifying transport to recycling facilities. Nevertheless, most commercially available compactors are designed for large-scale industrial use, rendering them unsuitable in terms of cost, size, and maintenance requirements for vocational training environments like KVSB (Hausmann et al., 2020; Scheid, 2018). This gap underscores the need for a small-scale hydraulic chip compactor tailored to the needs of training workshops, thereby addressing the technological shortfall in waste compaction applications within technical education institutions.

**Corresponding author: m-6207597@moe-dl.edu.my*

This research also contributes to the current scientific discourse on industrial waste management by focusing on the integration of user-friendly, cost-effective, and sustainable hydraulic compaction technology. By developing a hydraulic chip compactor specifically for vocational workshop use, this study not only responds to the practical needs at KVSB but also enriches academic discussions surrounding solid metal waste management in the context of technical education.

2. Methodology

2.1 Research Design

This research employed a developmental approach, focusing on the design, fabrication, and testing of a Hydraulic Chip Compactor. The project's execution was systematically planned using a Work Breakdown Structure (WBS), Gantt Chart, and flowcharts to ensure all objectives were met efficiently. The research was structured in three main phases: design, fabrication, and evaluation.

2.1.1 Design Phase

The initial phase involved project discussions, proposal development, and information gathering. The design for the hydraulic chip compactor was conceptualized through hand-drawn sketches which included key dimensions. These initial concepts were then developed into detailed 2D and 3D engineering drawings using Autodesk Inventor 2017 software. The final technical drawings included isometric, orthographic, and exploded views to guide the fabrication process. The design was optimized to save space in the workshop while ensuring user safety and efficiency in waste management.

2.1.2 Fabrication Phase

This phase followed the approved technical drawings. It involved the procurement of raw materials such as mild steel sheets, C-channels, and angle bars, as well as consumable components like a 10-ton hydraulic press and springs. The fabrication process included measuring, marking, cutting, welding (using the Gas Metal Arc Welding - GMAW process), grinding, and painting.

2.1.3 Evaluation Phase

The final phase focused on testing the functionality and quality of the finished product. This included a functional test run to assess the machine's performance in compressing metal chips and non-destructive testing on the weld joints to ensure structural integrity.

2.2 Research Procedure

The project was executed through a series of structured steps as seen on figure 1, commencing with a thorough planning phase that included project selection, proposal presentation, and the gathering of information on existing designs. Following this, the design and drawing stage involved creating initial sketches which were then developed into detailed technical drawings using Autodesk Inventor. With the designs finalized, the material procurement phase began, starting with the creation of a Bill of Materials (BOM) to guide the purchase of all necessary raw and consumable materials. The fabrication process then commenced, which involved measuring and marking the materials according to the drawings, cutting the parts to size, and subsequently fabricating and welding the main frame and its components. This was followed by finishing work, such as grinding and painting, to prepare the compactor for evaluation. In the testing phase, a functional test run was conducted to ensure the machine operated as intended, while the quality of the welds was verified through both visual inspection and liquid penetrant testing. Finally, after all tests were successfully passed, the project was finalized and prepared for presentation.

2.3 Data Analysis

Data analysis was conducted to evaluate the project, first The machine's effectiveness was evaluated qualitatively by comparing the volume and state of the metal chips before and after compression. A comparative table was also used to analyze the advantages of using the hydraulic compactor versus the manual method in terms of space, safety, and procedure. Then, the structural quality of the compactor was analyzed using data from non-destructive testing reports. The Visual Inspection Report and the Liquid Penetrant Test Report were analyzed against AWS D1.1 and ASME V Article 6 standards, respectively. The analysis focused on identifying any defects and determining whether the welds were of acceptable quality, resulting in an "ACCEPT" conclusion for the tested components.

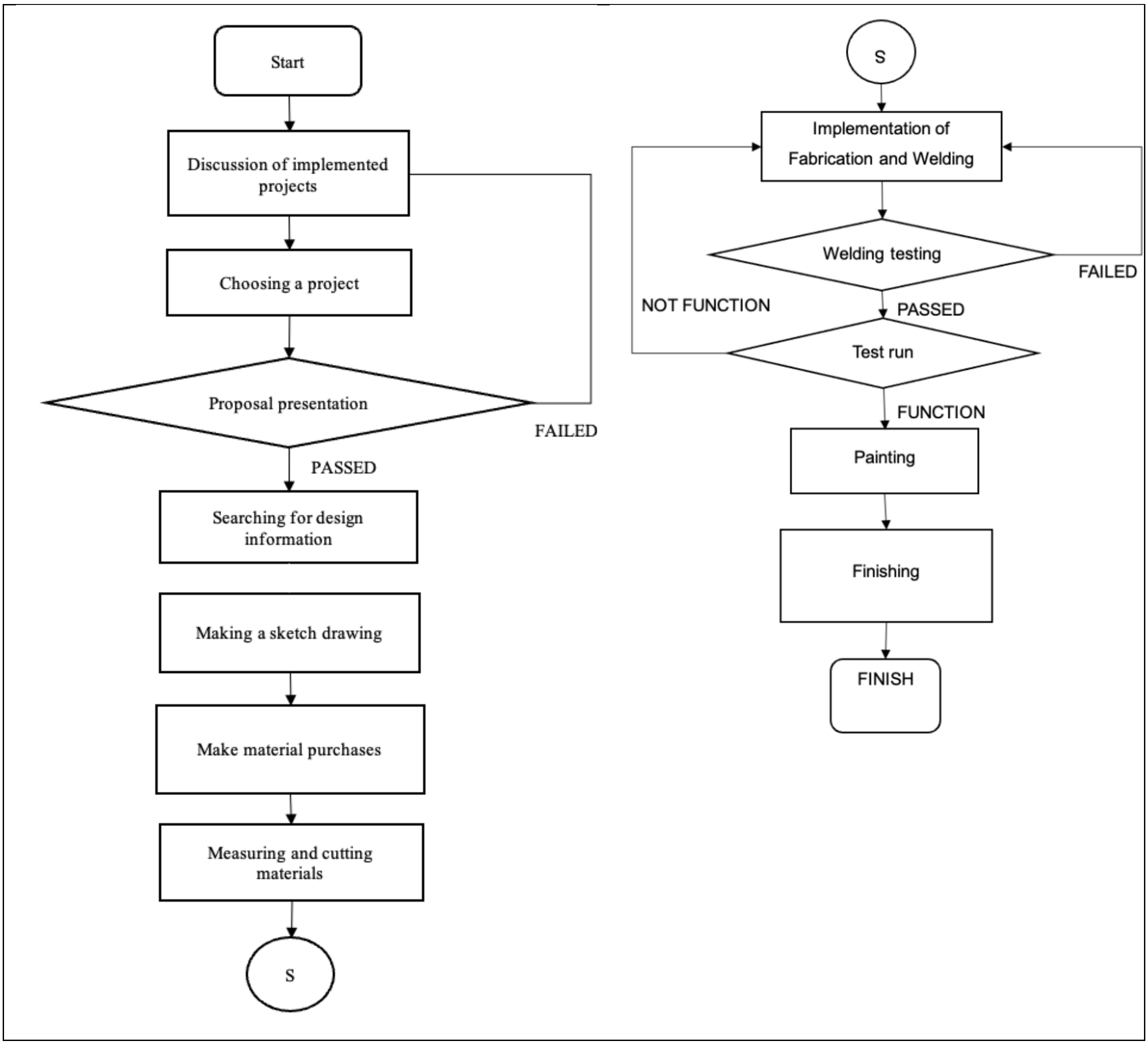

Figure 1. Flow Chart

3. Findings and Discussion

3.1 Design and Construction of the Hydraulic Chip Compactor

The primary finding of this phase was the successful fabrication of a functional, robust, and safe prototype of the Hydraulic Chip Compactor (HSC), constructed in accordance with validated technical drawings. However, a deeper discussion extends beyond merely confirming this success. As Brecher & Weck (2021) posits, the engineering choices made during the design and construction phases carry significant implications for the machine's suitability within its specific context.

The selection of mild steel for the structural frame was a strategic decision that balanced mechanical integrity (Xie et al., 2023), cost efficiency (Habeeb et al., 2018), and ease of fabrication (Asahi, 2013). Within the context of vocational education institutions—where financial resources are often limited—the optimization of material costs without compromising safety is a crucial factor (Juřicová & Vozňáková, 2017). Mild steel provides an adequate strength-to-weight ratio to withstand hydraulic compression forces of up to 10 tons, while also offering excellent weldability and machinability (Cadoni et al., 2018). These properties facilitated fabrication by students and technicians alike. This decision aligns with the principle of *design for manufacturability (DfM)*, which emphasizes ease of production as a core design criterion, particularly in non-industrial, small-scale environments (Fidan, 2004).

The verification of weld quality through both visual inspection and liquid penetrant testing, conducted in compliance with AWS D1.1 and ASME Section V standards, served as more than a simple quality control procedure. It represented the application of industry-level standards within an academic project setting. By ensuring the absence of critical defects such as cracks or incomplete fusion, the project not only guaranteed the long-term operational safety of the machine but also provided a pedagogical demonstration for students. This highlighted that even prototypes developed in workshop environments must adhere to rigorous professional codes and standards, effectively bridging the gap between academic theory and industrial practice (Shehab et al., 2017; Vedel & Irwin, 2017). As emphasized by Asahina et al. (2014), the structural integrity of the compression chamber directly affects the consistency and safety of the briquetting process—a principle empirically validated in this project.

Table 1. Findings on Design and Construction

Aspect	Findings in HSC
Structural frame	Mild steel, robust, stable
Hydraulic system	10-ton hydraulic press, stable force delivery
Welding quality	Passed AWS/ASME standards, no critical defects
Safety & reliability	Confirmed through inspection and test runs

3.2 Effectiveness of the Hydraulic Chip Compactor in Terms of Precision Results of Compressing Waste Scroll

Performance testing conclusively demonstrated that the HSC effectively converted loose metal chips into dense and uniform briquettes. This discussion extends beyond qualitative observations to consider broader quantitative and operational implications. The machine's capacity to significantly reduce waste volume—corroborating Simon et al.'s (2017) findings of up to 80% reduction—yields cascading effects on workshop efficiency.

First, from the perspective of *lean manufacturing* and the 5S methodology (Sort, Set in Order, Shine, Standardize, Sustain), the HSC directly contributes to the principles of *Seiri* (Sorting) and *Seiton* (Organizing). By compacting waste at the source, the machine reduces the frequency of bin emptying, frees valuable floor space, and fosters a tidier, less cluttered working environment. This reduction in disorder directly enhances workplace safety by minimizing risks of tripping and injuries from scattered sharp metal chips.

Second, the stable pressure applied by the manual hydraulic system ensures consistency in briquette density and dimensions. Such uniformity is critical for downstream recycling processes. Standardized briquettes are easier to stack, transport, and melt, thereby potentially increasing the commercial value of scrap metal. Consequently, the machine functions not only as a waste management tool but also as the initial step in a circular economy value chain, transforming waste from a mere operational burden into a potential asset (Vallejo-Olivares et al., 2021).

Moreover, the success of the HSC as a small-scale machine challenges the prevailing assumption that effective compaction technology must necessarily be large-scale and costly. This project demonstrates the feasibility of *appropriate technology*, tailored to the specific needs of end users—in this case, educational workshops. It also opens opportunities for adaptation in small and medium-sized enterprises (SMEs), which face similar waste management challenges but lack the capacity to invest in heavy industrial machinery.

Table 2. Findings on Effectiveness

Evaluation Criteria	Findings in HSC
Waste volume reduction	Compact, dense chip blocks
Consistency of results	Uniform blocks, reliable compaction
Safety improvement	Reduced risk of cuts and clutter
Suitability in workshops	High efficiency for small-scale use

3.3 Usability of the Hydraulic Chip Compactor

Positive reception from both students and instructors underscores the success of the design from a *human-factors engineering* perspective. Ease of operation, requiring only minimal training, is especially critical in educational environments. The intuitive design reduces users' cognitive load, allowing them to focus on the primary task—efficient waste management—rather than struggling with a complex interface. Furthermore, the manual hydraulic operation eliminates reliance on substantial external power sources, making the system cost-effective and operationally resilient.

However, the greatest value of the HSC in this context may lie in its dual role as both an operational tool and a pedagogical instrument. The machine serves as a tangible learning artifact. Students not only use it for workshop cleaning but also interact with a system that embodies fundamental engineering principles:

1. **Fluid Mechanics**: Direct engagement with Pascal's law demonstrates how hydraulic systems generate force multiplication.
2. **Materials Science**: The transformation of metal chips from low-density, high-volume material into dense briquettes provides a practical demonstration of material behavior under pressure.
3. **Sustainable Management**: The machine introduces students to concepts of sustainability and environmental responsibility, reframing waste management as an integral component of professional manufacturing practice rather than a peripheral task.

By integrating technologies such as the HSC into the curriculum, vocational education institutions can foster what are often termed *green competencies*. As argued by Robert et al. (2022), simple and scalable technologies are essential for educational applications, and this project serves as a prime example of that principle. The HSC not only addresses a practical challenge at KVSB but also enriches the learning experience, equipping students with relevant skills and awareness aligned with the demands of environmentally conscious modern industries.

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Table 3. Usability descriptions of HSC

Usability Aspect	**Findings in HSC**
Ease of operation	Simple to use, low training required
Physical effort reduction	Eliminated manual compression
Workshop cleanliness	Cleaner, more organized environment
Cost-effectiveness	Low maintenance, hydraulic-based

4. Conclusion

This study demonstrates that the development of a small-scale hydraulic chip compactor can effectively address key challenges in metal waste management within vocational workshop environments. Through a systematic design approach, the researchers successfully designed and constructed a machine that not only meets functional requirements but also complies with safety and ergonomic standards. Field performance testing confirmed that the machine operates consistently, compressing metal chips into dense blocks that save disposal space and enhance workplace cleanliness. Weld joint evaluations, conducted through non-destructive testing methods, verified that all structural connections fell within acceptable tolerance limits. In addition, positive user feedback indicated that the machine is easy to operate, safe to use, and well-suited for application in technical learning environments.

In conclusion, the hydraulic chip compactor achieved the main objectives of the study in terms of design, fabrication, and performance evaluation. The success of this project provides practical benefits to the KVSB workshop and contributes to the academic discourse on compaction technology and small-scale industrial waste management. The findings also suggest promising avenues for future research, including design refinement, control system automation, and the integration of smart technologies for real-time performance monitoring. Therefore, this machine holds strong potential for broader adoption in other educational institutions as well as small and medium enterprises (SMEs) seeking sustainable and cost-effective solutions for metal waste management.

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Conflict of Interest
The authors declare no conflicts of interest.

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