Development of a hydraulic jack system bending tool for improved manufacturing efficiency

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ABSTRACT

This article presents the design, fabrication, and testing of a hydraulic sheet metal bending tool. The main objective was to create a tool capable of bending sheets of various thicknesses, ranging from 2 to 4 mm, with high precision and minimal operator effort. The design incorporates a hydraulic ram for easy operation, allowing multiple plates to be bent in a short period of time. Key calculations, including bending force, spring load, and hydraulic force, are performed to ensure the efficiency and safety of the tool. Experimental results show that the tool is able to achieve the desired bending angles, with minimal spring return, and can handle up to three 10 cm wide sheets in approximately 10 minutes. The performance of the tool has been proven by tests, and the results confirm that it can meet the requirements of industrial sheet metal bending. Based on these results, the tool demonstrates its effectiveness in small and medium-scale operations, providing a cost-effective solution for sheet metal production.

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1. INTRODUCTION

The rapid advancement of manufacturing technology has significantly impacted the metal forming industry, enabling improved efficiency and precision in production processes. Among various metal forming techniques, sheet metal bending is widely utilized to fabricate components in automotive, aerospace, and construction sectors due to its ability to produce complex shapes with high accuracy [1]–[4]. Hydraulic bending machines have become popular because of their capability to exert high forces and adapt to different sheet thicknesses, offering flexibility in manufacturing [5]–[7].

Despite these advantages, conventional hydraulic bending systems often encounter challenges such as limited bending accuracy for thicker or larger sheets, inefficiencies in spring-back control, and poor mobility due to their bulky design [8]–[11]. These limitations especially affect small and medium enterprises (SMEs), which require cost-effective and versatile bending solutions to remain competitive [12]–[14]. Several researchers have explored improvements in bending tool design, including the integration of flexible tooling systems to enhance bending precision; however, the associated costs hinder widespread adoption in smaller workshops.

Recent innovations have also investigated the use of additive manufacturing for producing lightweight bending tools suitable for light-duty applications. Nakamura *et al.* [15] demonstrated the applicability of 3D-printed plastic tools for bending thin sheets, although mechanical strength limitations restrict their use for thicker metals. Furthermore, heat-assisted incremental bending methods have been proposed to achieve complex curvatures, but these techniques are often too complex and expensive for small-scale operations [16]. Other studies have addressed spring-back reduction and the optimization of spring mechanisms to improve tool performance and operator ergonomics [17].

Moreover, mobility remains a critical aspect for workshop tools, where integrating wheels or compact frames can significantly enhance operational flexibility and efficiency [18]. Current literature reveals a gap in developing hydraulic bending tools that combine precision, spring efficiency, and mobility, particularly tailored for SMEs and small workshops. This study aims to fill this gap by designing and fabricating a hydraulic jack system bending tool featuring an improved spring mechanism and integrated mobility via wheel mounting. The proposed design prioritizes operational ease, bending accuracy, and cost-effectiveness to support small and medium-scale manufacturing environments.

2. RESEARCH METHOD

This study follows a systematic engineering approach to design, fabricate, and test a hydraulic jack-based bending tool. It involves computer-aided design (CAD), component selection, and fabrication. Each stage is thoroughly documented to ensure valid and reproducible experimental performance evaluation.

2.1. Definition of bending tool

A bending tool is a machine used to bend materials such as metal, steel, plate, or wood to achieve the desired shape. The main purpose of the bending tool is to apply pressure to a specific part of the material, causing plastic deformation, and shaping it as required. Bending tool is a process that involves applying pressure to a material, resulting in plastic deformation [19], [20]. Bending tools are devices used to permanently alter the shape of materials through plastic deformation, creating the desired profile or shape.

2.2. Components of the bending tool

The bending tool consists of several key components. Seven main components: i) punch, ii) spring, iii) base plate, iv) pressure plate, v) slant die, vi) handle shaft, and vii) punch holder. The components as: i) shank (handle shaft), ii) punch, iii) base, iv) spring, v) top plate, vi) bottom plate, and vii) dies [21], [22]. Both references agree on the key components, but Werner's design, including the top and bottom plates, aligns better with the tool's function. This study focuses on the top plate, bottom plate, shank, and base plate.

2.3. Working principle of the bending tool

The bending tool applies compressive force to deform the metal and bend it to a specific angle, with precise control over the deformation to achieve accuracy [23]. The process depends on factors such as applied pressure, bending angle, and material properties. This method is widely used in industries like automotive and construction for metal forming.

2.4. Fundamentals of tool development

This section covers the key calculations for the hydraulic jack bending tool, focusing on bending force, spring load, hydraulic pressure, and structural strength to ensure safe and efficient operation:

i) Bending force calculation: the bending force required for the plate is calculated using (1) [24].

$$P = \frac{(UTS)\times L\times T}{W} \tag{1}$$

Where P is bending force (N), T is thickness of the plate (mm), L is length of the bending line (mm), W is die width (mm), and UTS is ultimate tensile strength (N/mm²). Figure 1 shows the punch and die components, where the punch applies force, and the die supports the plate, defining the bending angle and shape.

ii) Material mass calculation: the mass of the material is calculated using (2) [24].

$$W = V \times \rho \tag{2}$$

Where W is mass of the material (kg), V is volume of the material (mm³), and ρ is density of the material (kg/mm³).

iii) Pressure calculation: the pressure applied to the plate is calculated by (3) [24].

$$p = \frac{F}{A} \tag{3}$$

Where p is pressure (Pa), F is force (N), and A is area (m²).

iv) Spring load calculation: the spring load returns the punch to its original position after bending, overcoming friction and component weight. Proper calculation ensures smooth operation, durability, and efficiency during repeated use. The calculation method follows the approach developed by Ferhath and Kasi [25].
v) Hydraulic force calculation: the total hydraulic force is the sum of the bending force and spring force, subtracting the punch and bottom plate loads as in (4) [24].

$$F_{total} = F_{bending} + W_{spring} - W_{punch} \tag{4}$$

These calculations ensure that the bending tool operates efficiently and is capable of withstanding the required forces during the bending process.

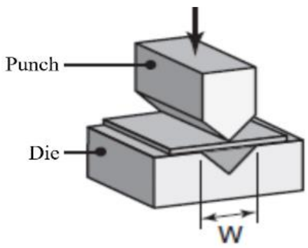


Figure 1. Punch and die

2.5. Location and time of implementation

The hydraulic jack bending tool was developed and tested at Politeknik Negeri Ujung Pandang's Mechanical and Welding Workshops. These workshops were chosen for their facilities, skilled personnel, and proximity. The project ran from December 2023 to March 2024, covering design, manufacturing, and evaluation.

2.6. Design and component selection

The design phase utilized Autodesk Fusion 360 to create detailed schematics of the tool components, ensuring precision in measurements and compatibility among parts. Key components include the punch, die, top plate, bottom plate, springs, and a 20-ton hydraulic jack. Steel plates were selected for structure, and carbon steel springs for resilience, ensuring durability and performance.

2.7. Fabrication procedure

The fabrication process consists of several stages:

i) Material preparation: steel plates were measured and cut using a grinding machine and milling tools to achieve the desired dimensions.
ii) Design: the fabrication process involves measuring and cutting steel plates with grinding and milling tools, followed by creating detailed component designs using Autodesk Fusion 360 software [12]. Figure 2 shows the main components of the bending tool; where Figure 2(a) is main frame, Figure 2(b) is died mount, Figure 2(c) is table, Figure 2(d) is bottom plate, Figure 2(e) is punch, Figure 2(f) is top plate, Figure 2(g) is died, Figure 2(h) is stand, and Figure 2(i) is shaft. Each part is precisely fabricated for durability and precision in the final assembly.
iii) Manufacturing: the fabrication process includes precise machining and assembly. Table 1 lists the steps for each component, covering tools, materials, and procedures like cutting, milling, drilling, and welding, ensuring parts meet design specifications for optimal performance. It also presents the components fabricated, the equipment utilized in their production, the types of materials employed, and the step-by-step manufacturing processes for each component.
iv) Assembly: after fabricating the components, they are assembled into the final hydraulic jack system bending tool, ensuring precise alignment and secure fastening for optimal performance. Figure 3 illustrates the complete assembly, showcasing its compact design and key functional elements.

2.8. Testing setup

The testing setup was designed to evaluate the tool's performance in bending accuracy, force efficiency, and mobility. Plates of varying thicknesses (2-, 3-, and 4-mm) were bent to target angles, while hydraulic force and spring load were monitored for consistency. The tool's mobility within a workshop setting was also assessed to ensure optimal performance under various conditions.

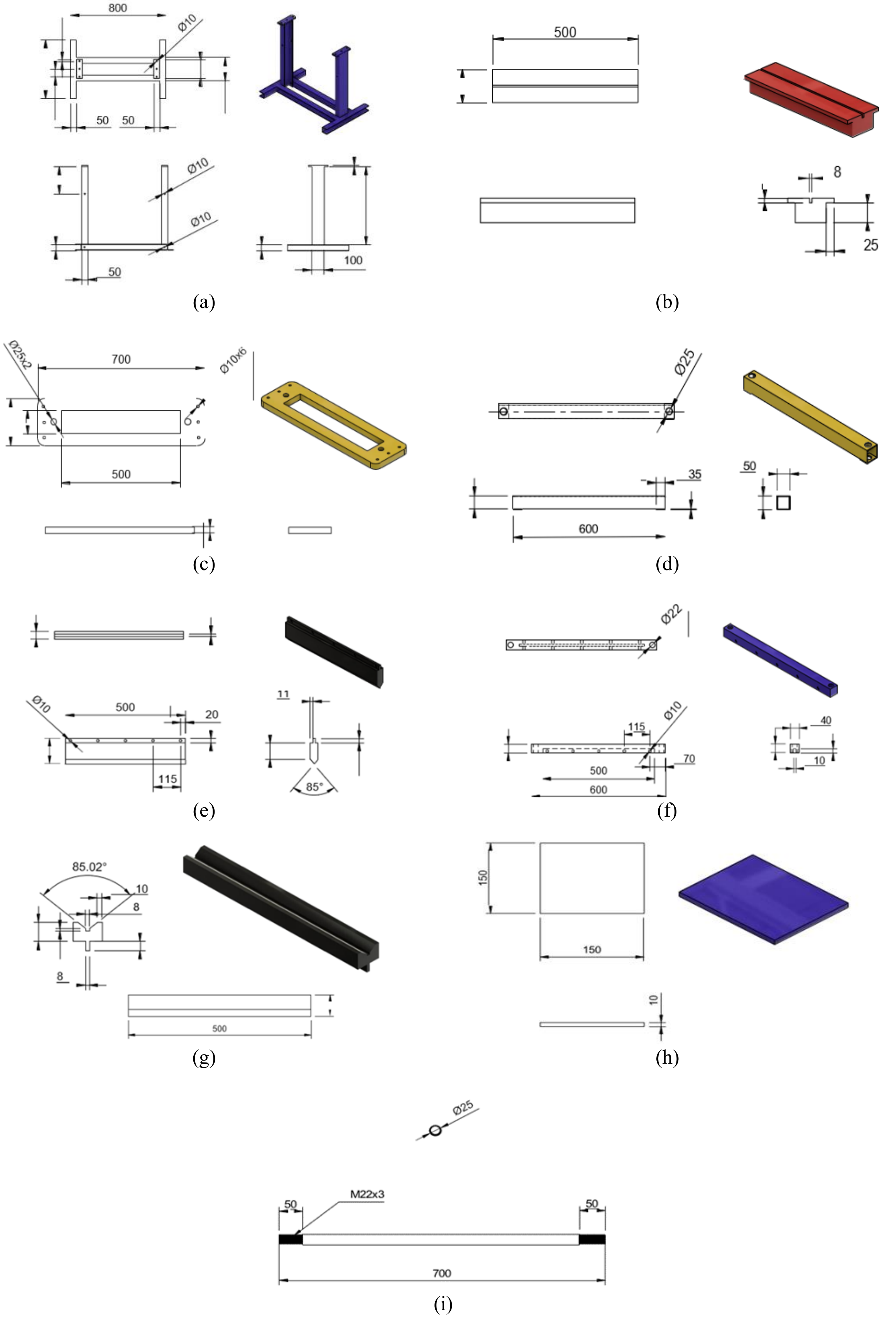
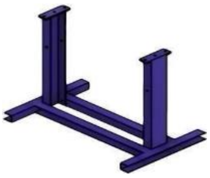
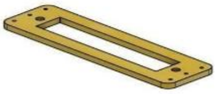
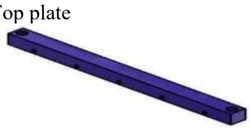
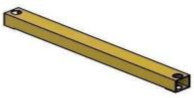


Figure 2. Main components of the bending tools of (a) main frame, (b) die mount, (c) table, (d) bottom plate, (e) punch, (f) top plate, (g) die, (h) stand, and (i) shaft

Figure 3. Hydraulic jack system bending tool

Table 1. Making bending tool components

No	Component	Tool	Materials	Manufacturing process
1	Main frame 	– Grinding machine – Meters – Electric welding machine	UMP 50, UMP 100	Measure the ump iron to the required size, then cut it using a grinding machine. Afterward, connect the pieces with electric welding and secure them with bolt connections as per the drawing.
2	Table 	– Grinding machine – Meters – Milling machine	20 mm Plate	Measure the plate to the required size, cut it using a grinding machine, then flatten the side plates and cut a hole in the middle to the specified size using a milling machine.
3	Stand 	– Grinding machine – Meters – Milling machine	10 mm Plate	Measure the plate to the required size, then cut it using a grinding machine.
4	Die holder 	– Grinding machine – Meters – Milling machine	Iron solid box	Measure the iron box to the required size, then cut the metal box using a chainsaw. Use a milling machine to create a hole in the middle to the specified size.
5	Die 	– Grinding machine – Meters – Milling machine	Iron solid box	Measure the iron box to the required size, cut the metal box using a chainsaw, and then use a milling machine to shape the die to the specified size.
6	Top plate 	– Grinding machine – Meters – Milling machine	Iron solid box	Measure the iron box to the required size, cut the metal box using a chainsaw, and then drill a hole to the specified size using a drilling machine.
7	Punch 	– Drilling machine – Sawing machine – Milling machine – Meters	Medium carbon steel	Measure to the required size, cut using a chainsaw, and then use a milling machine to shape the punch to the specified size.
8	Bottom plate 	– Grinding machine – Meters – Milling machine	Iron solid box	Measure to the required size, cut using a chainsaw, and then make a hole to the specified size using a drilling machine.

2.9. Flowchart

Figure 4 summarizes the research and development process of the hydraulic jack system bending tool. It outlines the steps from design to testing and evaluation. The flowchart provides a clear visualization of the project workflow, ensuring systematic execution of each phase.

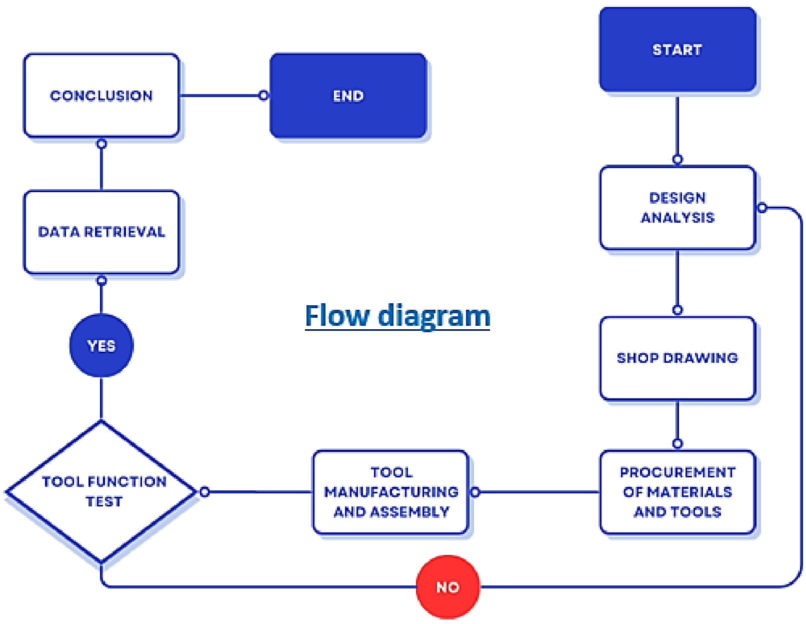


Figure 4. Fabrication and testing flowchart

2.10. Justification of methods

The chosen methodology ensures that the developed tool meets industrial standards in terms of precision, efficiency, and cost-effectiveness. The use of carbon steel springs significantly enhances the return efficiency of the punch mechanism, reducing energy loss and improving operational stability during repetitive bending cycles. In addition, the 20-ton hydraulic jack provides sufficient force to handle various material thicknesses with consistent accuracy, ensuring the tool's capability to perform under industrial conditions. Overall, these methodological choices guarantee reliable performance while maintaining affordability for small and medium-scale manufacturing applications.

2.11. Replicability

Detailed documentation of the fabrication and testing procedures ensures that the study can be replicated. The comprehensive methodology provides all necessary algorithms, calculations, and technical specifications. This allows for accurate reproduction of the tool.

3. RESULTS AND DISCUSSION

This section is organized to provide a critical interpretation of the findings, comparing them with existing literature, and identifying the implications and limitations of the study. This section highlights how the experimental results validate the theoretical calculations and demonstrate the performance of the hydraulic jack system bending tool under various operating conditions. Furthermore, it discusses the significance of the findings in improving manufacturing efficiency and examines how the proposed design addresses existing challenges identified in previous studies.

3.1. Design calculations

The design calculations were carried out to verify the strength and performance of the hydraulic jack system bending tool. Each calculation ensures that the tool operates safely under different loads and maintains bending accuracy. The main parameters analyzed include bending force, spring load, hydraulic force, welding strength, and bolt connection.

i) Bending force calculation: the bending force for plates of varying thicknesses (2-, 3-, and 4-mm) was calculated as follows: i) 2 mm thick plate: 4.435 N, ii) 3 mm thick plate: 9.979 N, and iii) 4 mm thick plate: 17.741 N (1.774 ton). The required force increases proportionally with material thickness, aligning with expectations based on material strength.

ii) Spring load calculation: the mass of components contributing to the spring load, including the top plate, punch, bottom plate, and die set, was calculated using the formula $W=V\times\rho$. The total spring load was then computed based on the mass of each component:

W_{total}=40.666 kg.

this means that the spring load is capable of handling up to 40.666 kg, which is within the safe operational limit of the system.

iii) Spring load and force: the spring's ability to return the punch to its original position was verified. With a capacity of 868.638 N, it can handle the required load, ensuring proper function within design limits.

iv) Hydraulic force calculation: the total hydraulic force required for bending the plate was calculated by summing the bending force and the spring load:

$$F_{total}=F_{bending}+W_{spring}=17.741\text{ N}+869\text{ N}=18.610\text{ N}=1.898\text{ kg}$$

given that the hydraulic jack has a maximum capacity of 20 tons, this is well within the safe operational range, indicating that the hydraulic system will be capable of handling the required forces.

v) Welding strength calculation: the strength of welded joints, particularly those securing the peg spring attachment, was analyzed using shear stress calculations. With a maximum load capacity of 148.470 N, well above the 17.741 N applied during operation, the welds are confirmed to be robust. Figure 5 highlights critical welding joints on the top plate hydraulic stands, crucial for maintaining structural integrity during bending operations.

vi) Bolt connection calculation: the bolt diameter required to withstand the applied forces was calculated to be approximately 11.014 mm. Based on this calculation, an M16 bolt with a diameter of 13.835 mm was chosen, ensuring that the connection would be secure and capable of handling the forces during operation.

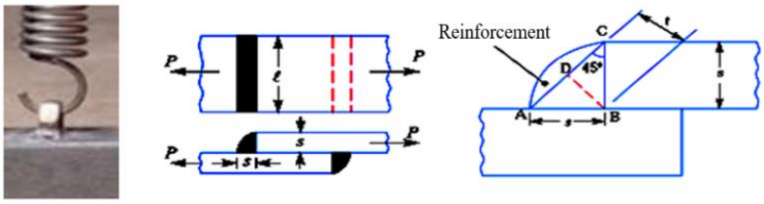


Figure 5. Critical welding joints on top plate hydraulic stands

3.2. Experimental results

The hydraulic jack system bending tool was tested using metal plates of varying thicknesses. The results confirmed that the tool could bend the plates accurately, with minimal spring-back, achieving the desired angles across all thicknesses tested. Table 2 shows bending test results, with angles near 90° and minimal spring-back (0° to 2°), indicating effective material control. Figure 6 compares pre- and post-bending samples, confirming the tool's accuracy and minimal distortion. Figure 6(a) shows the sample before bending, the initial flat metal sheet with the specified dimensions of 300 mm by 100 mm and varying thicknesses (2-, 3-, 4-mm). Figure 6(b) illustrates a sample after bending, the same metal sheet after being bent to the target angle, demonstrating the minimal spring-back and the high precision achieved by the hydraulic jack system bending tool. The comparison highlights the tool's effectiveness in controlling deformation and ensuring accurate bending results across different plate thicknesses.

The bending angles for the 2-, 3-, and 4-mm plates averaged 90.3°, 91.6°, and 90.3°, respectively, with minimal spring-back, confirming the tool's precision across various thicknesses. Compared to conventional hydraulic systems, the tool reduces spring-back while maintaining performance at lower cost and complexity. It performs within design limits, making it suitable for small to medium-scale sheet metal bending. Further research is needed for thicker materials and tougher metals, along with exploring automation for larger-scale applications.

3.3. Results overview

The bending tool was tested with plates of varying thicknesses, achieving high precision, minimal spring-back, and consistent performance, aligning with theoretical predictions. These results confirm that the hydraulic jack system bending tool performs effectively under different material conditions, maintaining accuracy and stability during operation. Furthermore, the close agreement between experimental and calculated values demonstrates the reliability of the design and validates the accuracy of the applied analytical approach.

Table 2. Bending test results

Sample	Plate size	Bending angle (°)	Spring back (°)
T2(1)	300×100×2 mm	90	0
T2(2)	300×100×2 mm	90	0
T2(3)	300×100×2 mm	91	1
	Average	90.3	0.3
T3(1)	300×100×3 mm	91	1
T3(2)	300×100×3 mm	92	2
T3(3)	300×100×3 mm	92	2
	Average	91.6	1.6
T4(1)	300×100×4 mm	90	0
T4(2)	300×100×4 mm	91	1
T4(3)	300×100×4 mm	90	0
	Average	90.3	0.3

(a) (b)

Figure 6. Comparison of bending samples of (a) sample before bending and (b) sample after bending

3.4. Comparison with previous studies

The findings were consistent with previous studies [26], demonstrating similar trends in bending precision and spring-back control. However, the present work achieved greater efficiency due to the improved spring mechanism and optimized hydraulic force application, which enhanced the tool's operational stability. In addition, the integration of mobility features distinguishes this study from earlier designs, making the tool more adaptable for use in dynamic workshop environments and small-scale manufacturing operations.

3.5. Limitations and future implications

The tool is suitable for small to medium operations, but further research is needed for larger-scale applications. It offers an economical solution for precision bending in automotive and construction. Future focus is on material diversification and automation for greater scalability.

4. CONCLUSION

This study developed a hydraulic jack system bending tool that addresses precision, efficiency, and mobility in metal bending. It successfully bends plates (2 to 4 mm) with minimal spring-back and improves productivity by bending multiple plates in 10 minutes, making it ideal for small to medium-scale manufacturing. The tool's compact design and spring mechanism provide a cost-effective solution for SMEs in sheet metal production. Future research should focus on adapting the tool for larger-scale applications, handling thicker materials, and integrating automation for improved speed and consistency. Further studies on long-term durability in diverse environments are needed to enhance scalability in the sheet metal bending industry.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

This study, supported by Politeknik Negeri Ujung Pandang through the DIPA program, was submitted to the International Journal of Advances in Applied Sciences (IJAAS) to meet research reporting and academic promotion requirements.

DATA AVAILABILITY

Data supporting this study's findings are available upon request from the corresponding author, [ANM]. Due to privacy and proprietary concerns, detailed data on bending tests and the experimental setup are not publicly available. No new data were created or analyzed; the results are based on experiments conducted at Politeknik Negeri Ujung Pandang's Mechanical and Welding Workshops.

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