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COLLEGE OF ENGINEERING, DESIGN, ART AND TECHNOLOGY

SCHOOL OF ENGINEERING

DEPAARTMENT OF MECHANICAL ENGINEERING

FINAL YEAR PROJECT REPORT

DESIGN AND FABRICATION OF A LOW-COST PNEUMATIC SHEET METAL CUTTING AND BENDING MACHINE.

BY

ATUGONZA WINNIE

STUDENT NO. 2100713424

REG. NO. 21/U/13424/PS

FINAL YEAR PROJECT REPORT SUBMITTED TO THE COLLEGE OF ENGINEERING DESIGN ART AND TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE AWARD OF BACHELOR OF SCIENCE DEGREE IN MECHANICAL ENGINEERING OF MAKERERE UNIVERSITY

MAIN SUPERVISOR: DR. EDMOND TUMUSIIME

CO- SUPERVISOR: ASSOC. PROF. OLUPOT PETER

DECLARATION

I, ATUGONZA WINNIE, hereby declare that the final year project report is prepared by me under the guidance of Dr. Edmund Tumusiime, my main supervisor.

Sign: ....AD.....

Date:...12th JUNE, 2025....

APPROVAL

This is to certify that the bearer ATUGONZA WINNIE has gone through a systematic process to come up with this final year project report titled, "Design and construction of a low cost pneumatic sheet metal cutting and bending machine". Therefore this serves to approve her final report submission to the department of Mechanical engineering under the school of Engineering, college of Design, Art and Technology, Makerere University with our due approval.

DR. EDMUND TUMUSIIME

SIGN: .....

DATE: 16/6/2025

MAIN SUPERVISOR

ASSOC. PROF. OLUPOT PETER

SIGN: .....

DATE: 17/6/2025

CO-SUPERVISOR

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LIST OF ACRONYMS

RRM	Roofings Rolling Mill
CGL	Continuous Galvanating Line
F	Force
QC/QA	Quality control/ Quality assurance

ABSTRACT

This project focuses on the design and fabrication of a low-cost pneumatic sheet metal cutting and bending machine suitable for small and medium-scale industries. The machine employs a double-acting pneumatic cylinder controlled by a 220V solenoid valve to automate cutting and bending operations on low to medium thickness sheet metals. The pneumatic system, operating at 6–8 bar pressure, provides rapid, reliable, and precise force application, reducing manual labor and improving productivity. The machine's compact and portable design allows easy handling and maintenance, while interchangeable punches and dies enable versatility in sheet metal processing. This approach offers an economical alternative to hydraulic systems, emphasizing simplicity, efficiency, and automation to meet industrial demands for quality and speed

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND INFORMATION

The development of modern manufacturing has always been driven by the need for efficiency, precision, and scalability. From the early days of manual craftsmanship to the industrial revolution's introduction of mechanized processes, the evolution of manufacturing technologies has significantly shaped industries worldwide. Sheet metal cutting and bending are fundamental operations in metal fabrication, critical to producing components used in a wide range of applications, from automotive parts to industrial machinery, household appliances, and construction materials.

Historically, metalworking relied heavily on skilled labor, with craftsmen using hand-operated tools such as shears, hammers, and presses to cut and bend metal sheets. While effective in producing custom parts, manual methods were labor-intensive, slow, and prone to human error, limiting their scalability in large-scale production. As manufacturing grew, particularly with the advent of mass production during the industrial revolution, there was an increasing need to automate these processes to meet rising demand (*The History of Pneumatics and Their Industrial Applications*, 2019.). The development of hydraulic and electrically powered machinery in the 19th and 20th centuries addressed this need, enabling faster, more accurate metalworking operations. Hydraulic presses, for instance, became widely used due to their ability to exert large forces necessary for shaping thick or rigid metal sheets (Turner, 2020). However, these machines came with significant costs—both in terms of initial investment and ongoing maintenance—making them inaccessible for small and medium-sized enterprises (SMEs) or local workshops. Over time, this led to a widening gap between large manufacturers who could afford high-tech solutions and smaller fabricators still relying on manual labor. In the broader context of global industry, the drive toward automation and efficiency has continued to grow. Modern manufacturing demands have moved toward lean production methods, with an emphasis on reducing waste, improving accuracy, and increasing production speed. For large-scale manufacturers, advanced technologies such as CNC machines, robotic arms, and fully automated fabrication lines have become the norm. However, these advanced technologies come with steep costs, not only in terms of purchasing but also in maintaining sophisticated machinery and training skilled operators.

At the same time, small-scale manufacturers, educational institutions, and low-budget workshops have been left behind by these advancements. While they may not require the full capabilities of expensive automated systems, they still need affordable solutions to enhance their productivity and meet the market's growing expectations for precision and efficiency. This has created a significant demand for low-cost, user-friendly alternatives that can deliver acceptable levels of accuracy and speed while remaining within budgetary constraints. Pneumatic technology, which uses compressed air to power mechanical operations, has emerged as a highly promising alternative to expensive hydraulic and electrical systems, particularly for small-scale and medium-scale operations (*The History of Pneumatics and Their Industrial Applications*, 2020.). The use of pneumatics in industry has grown due to several advantages:

- Cost-effectiveness: Pneumatic systems are generally less expensive than hydraulic or electrical systems. The materials used in these systems, such as pneumatic cylinders, valves, and compressors, are widely available and affordable.

- Simplicity: Pneumatic systems are easier to design, assemble, and maintain compared to hydraulic systems, which require more complex fluid management (Fakruddin et al., 2020.).
- Safety and Cleanliness: Pneumatic systems do not require oils or other fluids that can leak and create environmental or operational hazards. Compressed air is clean, making it ideal for environments where contamination must be avoided.
- Durability and Longevity: Pneumatic machines typically have fewer moving parts than hydraulic systems, reducing wear and tear and extending their lifespan with minimal maintenance (Pandita et al., 2020.).

Given these benefits, pneumatics presents an ideal solution for small-scale manufacturers and workshops seeking to modernize their operations without a substantial financial burden. Furthermore, pneumatic technology is well-suited for sheet metal cutting and bending, which require precise, repeatable movements that can be easily achieved with pneumatic cylinders and actuators. This project seeks to capitalize on the advantages of pneumatic systems by designing and fabricating a low-cost pneumatic sheet metal cutting and bending machine. The concept behind this project is rooted in the need to democratize access to efficient manufacturing technologies, providing an alternative to the high-cost hydraulic and electric machines that dominate the industry (Gujarathi et al., 2017.). By focusing on cost reduction, simplicity of design, and ease of use, this project aims to create a machine that meets the needs of smaller operations, workshops, and educational settings where budget constraints often limit access to advanced equipment. In the bigger picture, this project also aligns with global trends toward greater sustainability and resource efficiency. Pneumatic systems, due to their low energy consumption and minimal environmental impact, are more sustainable compared to hydraulics, which rely on oil and fluids. This project, therefore, not only addresses the economic need for affordable machinery but also contributes to the broader goals of sustainable and environmentally friendly manufacturing practices (Du et al., 2022).

The design and fabrication of a low-cost pneumatic sheet metal cutting and bending machine is a response to the growing demand for accessible, efficient manufacturing tools (Azundah et al., 2020.). By leveraging pneumatic technology, this project seeks to offer an alternative that fills the gap between manual labor and high-cost automation, providing smaller manufacturers with the means to compete in an increasingly automated and precise manufacturing environment. In doing so, it contributes to the ongoing efforts to make modern manufacturing tools more accessible, cost-effective, and sustainable, benefiting industries, institutions, and individuals alike.

The shearing and bending machine is most important in sheet metal industry. This machine should be used for straight cutting machine with wide application. But in some industry hand sheet cutter and bender are used (Gaur et al.,2016.). For that machine to operate, the human effort is required. The machine should be simple to operate and easy to maintain, hence I have tried out to develop the pneumatic shearing and bending machine. In shearing or cutting operation as the punch descends upon the metal, the pressure exerted by the punch first cause the plastic deformation of the metal. Since the clearance between the punch and the die is very small, the plastic deformation takes place in a localized area and the metal adjacent to the cutting edges (Pratihar et al., 2022.). In bending operation on the bend has been made with the help of punch which exerts large force on the work clamped on the die. The bending machine is designed in such a way that, it works automatically. The machine is designed by observing the factors to improve efficiency and to reduce the cycle time by producing quality output(Gaur

et al., 2016.). Automation of machine is achieved with the help of pneumatic system. This involves the design of an efficient system which reduces the human effort and help to increase production output. It also includes pneumatic system, pneumatic component and shearing die and bending die.

1.2 PROBLEM STATEMENT:

Small-scale manufacturing industries and workshops face significant challenges in sheet metal cutting and bending due to the limitations of available tools. Manual methods, though affordable, are labor-intensive, error-prone, and inefficient, while automated hydraulic and electric machines, though precise and efficient, are prohibitively expensive and complex to maintain. This leaves small-scale industries struggling with outdated techniques or unsustainable investments, hindering productivity and precision. This project aims to bridge this gap by designing a low-cost pneumatic sheet metal cutting and bending machine, offering an affordable, efficient, and easy-to-maintain solution tailored to the needs of small-scale industries and resource-limited settings (*Cost-Effective Tips for Small-Scale Metal Fabrication*, 2020.).

1.3 OBJECTIVES

1.3.1 MAIN OBJECTIVE

To design and fabricate a low-cost pneumatic machine capable of performing both cutting and bending operations on sheet metal, suitable for small-scale industries and workshops.

1.3.2 SPECIFIC OBJECTIVES

To design a pneumatic system that provides adequate force for sheet metal cutting and bending operations.

To Fabricate and assemble a functional prototype, verifying cutting and bending capabilities at 90° and 45° angles

To test the prototype for cutting, bending, and efficiency, making design adjustments as needed

1.4 JUSTIFICATION

The justification for this project lies in addressing the practical needs of small-scale industries by providing a cost-effective, efficient, and versatile solution for sheet metal cutting and bending. Pneumatic systems offer affordability, simplicity, and low maintenance compared to expensive hydraulic and electric systems, making the machine accessible to workshops with limited technical expertise. Combining cutting and bending operations in a single, compact design saves space, reduces workflow inefficiencies, and minimizes costs. Using locally available materials and components ensures ease of fabrication and replication, while the machine's modular design allows flexibility to adapt to various applications. Additionally, its low energy consumption further enhances operational efficiency, making it an ideal choice for resource-constrained environments.

1.5 SIGNIFICANCE

The pneumatic sheet metal cutting and bending machine is a significant innovation for small-scale industries, offering an affordable and energy-efficient alternative to expensive hydraulic or electric systems. By automating cutting and bending, it enhances productivity, precision, and safety while reducing labor and operational costs. Its simple design ensures accessibility for operators with limited technical skills, and its use of locally available materials promotes self-reliance, local manufacturing, and economic growth. The machine's versatility and adaptability across industries like construction and automotive increase its value, while its sustainable design minimizes environmental impact. Additionally, this project fosters technical innovation and provides a practical learning platform for developing new material processing technologies.

1.6 THE PROJECT SCOPE.

The project aims to design, fabricate, and test a low-cost pneumatic sheet metal cutting and bending machine, focusing on efficient pneumatic systems, durable mechanical structures, optimized material handling for common metals, and affordability for small-scale industries.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Sheet metal bending is one of the most widely applied sheet metal-forming operations. The understanding of the bending mechanics is aimed at obtaining two kinds of information important for industrial applications. The first one is the spring back prediction for die design and shape control. The second is an estimation of the bend force for selection of press capacity, strength analysis and design of dies.

Sheet metal fabrication is a fundamental process in manufacturing, used to create components across various industries, including automotive, aerospace, and construction. Efficient, low-cost fabrication solutions are crucial for small- and medium-scale enterprises that aim to reduce production costs without compromising quality. Recent advancements in pneumatic systems offer promising applications in sheet metal machinery, enabling simpler, safer, and more cost-effective solutions compared to conventional hydraulic and mechanical systems(Awasthi et al., n.d.; Metals & 2020.).

2.2 Sheet Metal Fabrication Methods

Sheet metal processing typically involves cutting and bending, two key functions for shaping flat sheets into desired forms. Traditional fabrication methods rely heavily on hydraulic presses and manual labor, both of which can incur high costs. Hydraulic presses, for example, require maintenance and can be expensive due to the hydraulic fluid and power consumption needed to operate them (Smith & Jones, 2018). Alternatively, manual sheet metal work is labor-intensive, prone to inaccuracies, and not feasible for high-volume production.

Advancements in pneumatic systems address these issues by providing an alternative to costly hydraulic setups. Pneumatic systems operate using compressed air, which is abundant and inexpensive, making them ideal for low-cost fabrication equipment (Tanaka, 2020). These systems also tend to be more environmentally friendly, as they do not rely on hydraulic fluids that may pose ecological risks if improperly disposed of.

2.3 Pneumatic Systems in Fabrication Machinery

Pneumatic systems have gained popularity for their ease of use, low cost, and simple maintenance compared to hydraulic systems. Compressed air is used to power pistons and actuators, which in turn drive cutting and bending tools with high precision. Research by Wang et al. (2019) demonstrated that pneumatic-powered presses could achieve performance levels comparable to hydraulic presses while maintaining lower costs and simpler designs. This makes them particularly attractive for small-scale industries where budget constraints are a priority (Bracco, 2016).

The use of pneumatic systems in fabrication equipment offers several advantages:

- **Cost-Efficiency:** Air compressors are cheaper and easier to maintain than hydraulic pumps, making pneumatic systems suitable for budget-conscious setups (Kumar & Singh, 2021).
- **Environmental Safety:** Since pneumatic systems do not rely on hydraulic fluids, they eliminate the risks associated with fluid leaks and disposal (Liu & Hu, 2019).

- **Reduced Maintenance Requirements:** Pneumatic systems tend to have fewer moving parts and are less prone to overheating, reducing the need for frequent maintenance (Gupta & Patel, 2022).

These characteristics make pneumatic systems ideal for integration into low-cost, dual-function machines designed to cut and bend sheet metal.

2.4 Dual-Function Sheet Metal Machines

Integrating cutting and bending functions into a single machine presents a substantial advantage in terms of space, time, and cost savings. In traditional setups, cutting and bending are performed on separate machines, requiring operators to move materials between stations. Research by Chen and Zhou (2017) indicates that dual-function machines reduce material handling time by approximately 30% and increase workflow efficiency in small workshops.

The dual-function design also minimizes floor space requirements, a critical consideration for smaller workshops (Patel et al., 2020). By consolidating functions, dual machines reduce the overall equipment footprint, which allows for easier machine operation and maintenance.

2.5 Combining Pneumatics with Dual Functionality

In developing a low-cost, dual-function pneumatic sheet metal cutting and bending machine, this project seeks to combine these benefits into a compact, efficient, and cost-effective solution. The proposed machine would leverage pneumatic systems to power both cutting and bending operations, allowing small and medium enterprises to achieve industrial-grade quality without the high costs associated with hydraulic or high-end mechanical machines. Here an attempt is made to review the status of literature in pneumatic based on various criteria. The work done by various authors are explained below

Vallance and Matlock (1992) studied the friction behavior of zinc-based coated sheet steels and laboratory scale friction analysis techniques that involve sheet sliding over cylindrical dies. Mai Huang and Gardeen (1994) presented the literature review of the springback of doubly curved developable sheet metal surfaces and provided a bibliography on the springback in sheet metal forming. Reviewing the literature, it is found that researchers have been studying the phenomenon of springback for nearly six decades. There have been diverse efforts to evaluate and or decrease springback in the sheet metal forming industry for long time. Perduijn and Hoogenboom (1995) derived a simple explicit bending couple curvature relation for small and larger curvatures and they verified the model with experimental results. Saanchez (1999) focused on a systematic analysis of testing equipment as a measurement system of the friction phenomena on sheet metal under plain strain. It provides experimental references in order to optimize the usage of lubricants and sheet metal.

Samuel (2000) analyzed the springback the axisymmetric U-bending processes with a finite element program and discussed the effect of tool geometry and blank holder force on the final shape after springback. Aleksy et al (2001) conducted experiments on springback for dual phase steel and conventional high strength steel for a hat channel section with varying cross sections. They described the methodology of experiments and discussed springback related results. Carlos Gomes et al (2005) investigated the variation of springback in high strength steels based on experimental and numerical analysis. Dongye Fei and Peter Hodgson (2006) investigated the variation the springback behavior of cold rolled transformation induced

plastically (TRIP) steels in air v-bending process. Se youngkim et all (2007) examined the effect of tool design and process parameters on the springback of GLARE and the parameters studied include punch radius, punch speed, forming load and forming temperature.

In cutting operation as blade descends upon the metal, the pressure exerted by the blade first cause the plastic deformation of the metal. Since the clearance between the two blades is very small, the plastic deformation takes place in a localized area and the metal adjacent to the cutting edges of the blade edges becomes highly stressed, which causes the fracture to start on both sides of the sheet as the deformation progresses and the sheet is sheared (*Design and Analysis of Multipurpose Machine for the Productivity of Sheet Metal Process*, 2020.).

2.6 Types of cutting or shearing machines

1. Pneumatically operated
2. Hydraulically operated.
3. Rack and pinion operated
4. Spring operated.

2.6.1 Brief description of all the types is as follows:

1. Pneumatically operated. Here the advancement of the header is carried out in the upward and downward direction using the pneumatic double acting piston and cylinder unit arrangement along with the foot operated direction control valve. In this type of machine high pressure air is used as the working fluid for the transfer of power and the motion (*Pneumatic System Design of Bending Machine | HARSLE*, 2020.).
2. Hydraulically operated. Here the lowering and raising of the header is carried over using hydraulic piston and cylinder arrangement. To actuate the piston and cylinder, the oil is allowed to enter the cylinder from front or the back side of the piston. But the oil is comparatively costlier and its leakage may cause so many problems (*Hydraulic Cutting Machine - All Industrial Manufacturers*, 2023.).
3. Rack and opinion operated. Here the lowering and the raising of the header are carried out manually using direct hand pressure on the rack and pinion arrangement. In this case the required pressure is applied manually using direct hand pressure on the rack using pinion and lever arrangement. Since the machine is robust and requires large pressure, hence it is not suitable (Pratihar et al., 2020).
4. Spring operated. The working of the spring-operated machine is similar to the rack and pinion operated machine but differs in the construction. Here the lowering and the raising of the heating handle are carried out manually and it requires too much pressure for its operation and also there is the possibility of having damage to the work piece if not handled carefully.

CHAPTER 3: METHODOLOGY

The aim of this project is to design and fabricate a low-cost combined pneumatic sheet metal cutting and bending machine. Combining the two together to make one machine.

3.1 Introduction

This chapter introduces to the methods that were followed to achieve both the main and the specific objectives of this project. The sheet metal cutting and bending machine works with the help of pneumatic double acting cylinder. The pneumatic cylinder was connected to the moving cutting or bending tool. It is used to cut and bend the small size of the sheet metal. The machine is relatively portable in size compared to the existing ones, so easily transportable. The compressed air was used as the force medium for this operation. There is pneumatic single acting cylinders solenoid valves, flow control valve. The sheet metal cutting process is a main part of the all industries. Normally the sheet metal cutting and bending machine is manually hand operated one for medium and small scale industries. Automation in the modern world is inevitable

3.2 Determination of the design requirements.

This was achieved by collecting detailed information regarding the use, possible improvements and challenges presented employees of RRM especially those under QA/QC at CCL and CGL.

Data collection techniques

Document Review.

The manuals for cutting and bending machines were accessed from the internet and read in order to understand the essential functions bending and cutting machine must incorporate in order to effectively bend and cut sheet metals. They provided information about cutting element, bending and other necessary information.

Field observation.

The workers were always observed moving from one point to another struggling to cut and bend at different times which was real hectic. The existing cutting machine was so heavy and also unsafe for people to use it in a short time as shown in the diagram below



Figure 1: Manual cutting machine at RRM ,CGL

Interviews.

The interview guides used focused on knowing how much each machine costed initially to purchase it, the challenges faced while using the two different machines separately. This informed was mainly to supplement the one obtained from field observation.

Through interviewing the manager of CGL line at RRM, Namanve, Mr. Bwengye Innocent, the needs statement for the pneumatic sheet metal cutting and bending machine was developed as shown in table below.

Table 1: Interviews for data collection

S/N	Statement	Need
1	Manual cutting machines	Automated one which requires less labor
2	Time consuming because the existing ones are separately made so the movements from one machine to another is time consuming	Combined cutting and bending machine to reduce on time wastage
3	Initial costs for purchasing only cutting machine is so high and bending too which is not affordable by most small scale industries	Combined one to reduce on the initial costs
4	Unsafe for workers due to ergonomic hazards	Safer machine
5	You see these machines when they are separate and manual especially the cutting machine, the costs of production becomes high. For example watch these CGL boys struggling to cut and bend during quality control and assurance, we have employed many of them so that others can handle bending and others cutting which so costly	A combined machine is a better option

Field observations.

Through observing from the field, the following were noted;

The existing bending manual machine costs shs UGX: 7,865,348.81 and the existing pneumatic cutting machine costs shs UGX: 10,057,7862.11which is so expensive

Unsafe for users. Due to too much human involvement in the manual cutting machine, the users are exposed to risks like cutting of their body parts like fingers and many others

Design requirements and specifications.

Sheet metal made of aluminum/ material size- thickness = 0.5mm and length of cut= 25mm

Maximum shear strength of aluminum = 30N/m2

The machine was made of mild steel and use a 12 volt air compressor that develops 10.34 bars of pressure.

The bending part was designed to bend the sheet metal at 45 and 60 degrees

Prioritize safety of the operator and the passerby.

The bending part was designed in such a way that it is adjustable.

Relatively low cost compared to the existing ones.

3.3 Research design

The research design was based on combination of both qualitative and quantitative design that helped in making valid conclusions. The results are used to make a suitable design and prototype for the project. Qualitative design involves the analysis of unstructured information. The raw data collection is to be done using both direct interview and benchmarking in order to gather all the necessary information. The different techniques that are used for data collection include; interviews, observation, journals, textbooks and analyzing existing metal sheet cutting and bending machines. `Quantitative design included all the required procedures for designing and construction of all the necessary parts of a pneumatic sheet metal cutting and bending machine, the selection of materials, determining the required properties analysis, capacity of the machine in regards to cutting and bending sheet metal to angles at the required angles needed to be used in the quality testing, speed and time.

3.4 Concept Development

This involved the following steps

3.4.1 Identification of key Functional Requirements

Cutting and Bending Operations: The machine must efficiently perform both cutting and bending of sheet metal.

Pneumatic System: Utilize compressed air to power the cutting and bending mechanisms.

Cost-Effectiveness: Design should minimize material and operational costs to ensure affordability for small-scale manufacturers.

Ease of Operation: The machine should be user-friendly, requiring minimal training for operators.

3.4.2 Initial Concepts

Concept 1: Manual Combined Cutting and Bending Machine

A machine that uses a pneumatic cylinder to drive a shearing blade for cutting sheet metal.

Components: Piston cylinder, cutting blade, frame, levers.

Advantages: Simple design, effective for straight cuts, low maintenance.

Concept 2: Combined hydraulic presses for cutting and bending sheet

A machine designed specifically for bending operations using pneumatic actuators.

Components: Pneumatic actuator, bending die, control system.

Advantages: Focused on bending accuracy, can handle various sheet thicknesses.

Concept 3: Pneumatic (Semi-Manual) Combined Cutting and Bending Machine

Description: A multifunctional machine that integrates both cutting and bending operations in one unit.

Components: Dual pneumatic cylinders (one for cutting, one for bending), a shared control system, adjustable dies.

Advantages: Versatile, saves space and cost by combining operations.

Concept 4: Automated Pneumatic Cutting Machine

Description: An automated system controlled by sensors and an electronic circuit to perform cutting operations at set intervals.

Components: Pneumatic cylinder, electronic control circuit, sensors, automatic feed mechanism.

Advantages: High efficiency, reduced manual effort, consistent results.

3.4.3 Concept Evaluation Criteria

The following were established criteria for evaluating each concept based on:

- Cost of materials and components
- Complexity of design and assembly
- Performance metrics (cutting speed, accuracy)
- User-friendliness
- Maintenance requirements

3.4.4 Scoring Matrix

Create a scoring matrix to compare each concept against the evaluation criteria. Assign scores from 1 (poor) to 5 (excellent) for each criterion. Concept selection.

Table 2: Scoring matrix criteria

Concept	**Cost**	**Complexity**	**Performance**	**User-Friendliness**	**Maintenance**	**Total Score**
Manual Combined Cutting and Bending Machine	4	3	2	3	3	12
Pneumatic (Semi-Manual) Combined Cutting	3	4	5	4	4	20

and Bending Machine						
Automated Pneumatic Cutting and bending Machine	1	2	5	4	2	14
Combined hydraulic presses for cutting and bending sheet	1	1	5	3	2	12

3.5 Concept Selection

Based on the total scores from the evaluation, the Pneumatic (semi-manual) cutting and bending Machine (Azundah et al., 2019.) Scores the highest (20 points), making it the most feasible option due to its simplicity, cost-effectiveness, and ease of operation. The next best option is the automated Pneumatic cutting and Bending Machine, which can be considered for future enhancements or as an additional feature in subsequent iterations.

The selected concept will be further refined through detailed design work, including CAD modeling and simulation testing. This approach ensures that the final design meets the functional requirements while remaining accessible to small-scale manufacture

3.6 Construction Details

Main Components of pneumatic (semi-manual) bending and cutting machine are listed below.

3.6.1 Base Frame and support structure

The Primary base frame was the base element provided four pieces of hollow square bars, The primary base is made of mild steel square tube and mild steel plate. It supports the entire assembly of the pneumatic metal sheet bending and cutting machine system

The machine's frame and support structure must withstand the forces generated during cutting and bending operations. It should be designed to ensure the machine's rigidity and stability.

Stress Analysis: To prevent structural failure, the frame must be able to handle the forces without exceeding the material’s yield strength. The basic stress equation is:

$$\sigma = FA$$

Where:

σ = Stress (Pa)

F = Force applied to the frame (N)

A = Cross-sectional area of the frame material (m^2)

The stress must be lower than the yield strength of the frame material to ensure safety.

3.6.2 Cutter mechanism:

The cutting blade needs were designed to cut through the sheet metal effectively. The key design considerations include blade material, thickness, and the angle of the blade (shear angle).

Shear Force: The force required to cut the sheet metal depends on the material properties, the thickness of the sheet, and the cutting length. The shear force Fs can be estimated using the equation:

$$Fs = \tau \times t \times l$$

Where:

Fs= Shear force (N)

τ = Shear strength of the sheet material (Pa)

t = Thickness of the sheet (m)

l = Cutting length (m)

Blade Angle: To reduce the required cutting force, the blade is often angled. The relationship between the cutting force and the blade angle θ, can be approximated as:

$$Fc = \sin(\theta) Fs$$

Where:

Fc= Cutting force with angled blade (N)

θ = Blade angle

Removing of metal by a rotating abrasive wheel. (Very high speed, Shallow cuts)•the wheel action similar to a milling cutter with very large number of cutting points. Any material of dimension within the capacity of the wheel that can be cut off by sawing, shearing flame cutting can be cut off with a properly selected abrasive cutting- off wheel. It is used for all metals including such hard and tough ones as hardened tool steels and

Stainless steel. Within its scope are rods, tubes shapes and sheets of plastics, brick , tile stone, porcelain carbon, hard rubber state and casein .Many of these materials cannot be satisfactorily cut with a saw. This mechanism is run by A.C. Supply.

3.6.3 Pneumatic cylinder:

Pneumatic cylinder(s) (sometimes known as air cylinders) are mechanical devices which use the power of compressed gas to produce a force in a reciprocating linear motion .Like hydraulic cylinders, something forces a piston to move in the desired direction. The piston is a disc or cylinder, and the piston rod transfers the force it develops to the object to be moved. Engineers sometimes prefer to use pneumatics because they are quieter, cleaner, and do not require large amounts of space for fluid storage. Because the operating fluid is a gas, leakage from a pneumatic cylinder does not drip out and contaminate the surroundings, making pneumatics more desirable where cleanliness is a requirement.

The pneumatic cylinder is the core component responsible for providing the force required to perform both cutting and bending. The design of the pneumatic cylinder includes determining its dimensions, stroke length, and force requirements.

Force: The force generated by a pneumatic cylinder is a function of the air pressure applied and the area of the piston. The force can be calculated using the equation:

$$F=P\times A$$

Where:

F = Force exerted by the cylinder (N)

P = Air pressure (Pa)

A = Cross-sectional area of the piston (m^2), calculated as $A=\pi\times(d/2)2$

d = Diameter of the piston (m)

The required force F must be greater than or equal to the cutting force or bending force needed for the metal sheet.

Stroke Length: The stroke length of the cylinder is determined based on the travel distance required to perform cutting or bending.

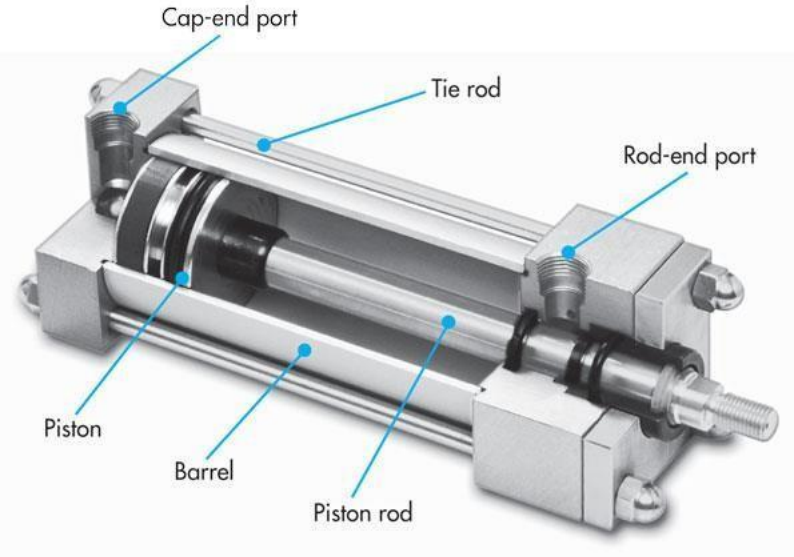


Figure 2: Pneumatic cylinder

3.6.5 Cutter

The Universal Tool & Cutter Grinder is a robust machine capable of dealing with a wide range of tool & cutter

Grinder operations. It is available as a steel cabinet mounted, machine and is designed for the rapid sharpening of H.S.S. milling cutters, spiral mills, metal slitting saws side and face cutters reamers, tap and with suitable attachments lathe tools, end mills formed cutters and many others.

3.6.6 Bending blade

The angled bar were used for the bending part to bend the sheet metal.

- **Bending Force**: The force required for bending depends on the sheet metal's material, thickness, and the length of the bend. For V-bending, the bending force Fb can be calculated using:

  $Fb=k\times\sigma y\times L\times t2VF$

  Where:

  Fb = Bending force (N)

  k = Constant (usually between 1.3 and 1.5 for V-bending)

  σy = Yield strength of the material (Pa)

  L = Length of the bend (m)

  t= Thickness of the sheet (m)

V = angled bar width (m)

The die opening V is generally selected to be 6 to 8 times the sheet thickness for optimal bending results.

3.6.7 Air Compressor and Pneumatic System Design

The pneumatic system needed to supply compressed air at sufficient pressure and flow rate to operate the pneumatic cylinder efficiently.

Air Consumption: The air consumption Q of the pneumatic cylinder can be estimated using:

$$Q=60A\times S\times N$$

Where:

Q = Air consumption (L/min)

A = Cross-sectional area of the piston (cm^2)

S = Stroke length (cm)

N = Number of strokes per minute

The air compressor should be selected to meet this demand with some margin to ensure smooth operation.

3.6.8 Springs

Springs were used for bending part for adjusting the bending of the bending blade according the sheet sample used

Spring Force: The spring force Frequired to be calculated using Hooke's law:

$$F=k\times x$$

Where:

F = Spring force (N)

k = Spring constant (N/m)

x = Displacement or distance of the spring (m)

CHAPTER 4: DESIGN, TESTING RESULTS AND DISCUSSION

4.1: Preliminary Design Of A Pneumatic Bending And Cutting Machine.

4.1.1. Rough sketches of the design

Below were some of the hand sketches made while brainstorming on the exact design that was to be effective

As seen below.

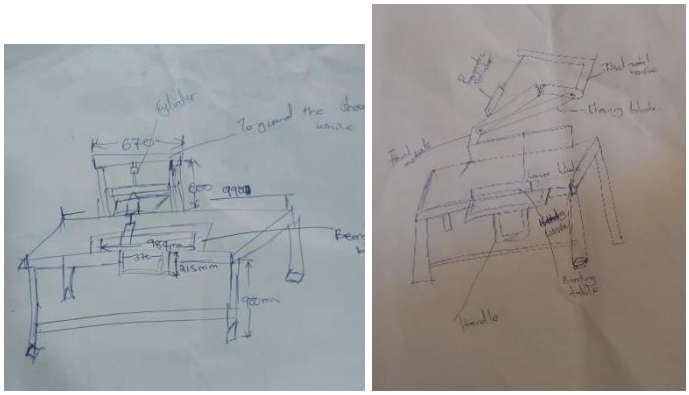


Figure 3: Sketches made while brainstorming

4.1.2 Embodiment design

The system layout of the functional components of the low cost pneumatic sheet metal cutting and bending machine was developed. This was based on its principles of operation.

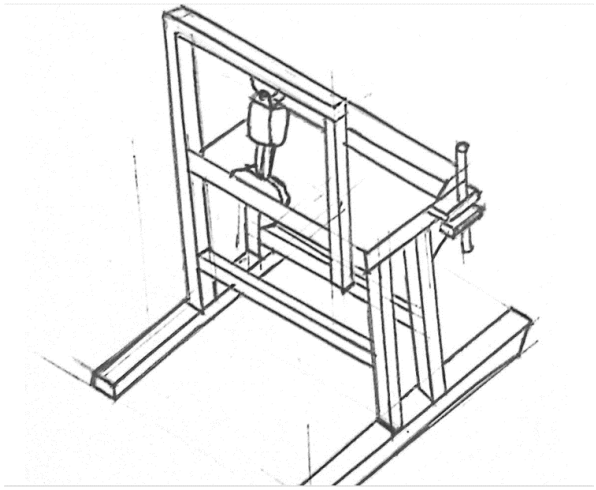


Figure 4: Hands-on sketch

4.2 Detailed design per component.

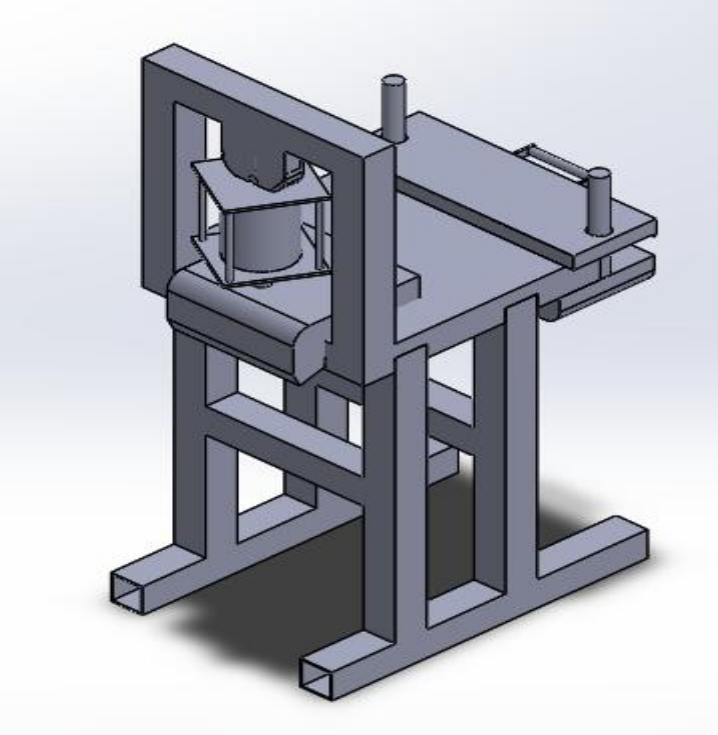


Figure 5: A detailed CAD design of the prototype

4.2.1. Parametric design per component

This involved sizing the key components of the machine such as the base frame, cutting part, pneumatic cylinder and the bending part.

4.2.1.1 Base frame.

This supports the whole system. It comprised of four hollow square bars and a rectangular surface.

Primary variables include

Material: Mild steel (MS)- Affordable, weldable, of allowable stress, As=120-140 MPa

Load capacity: 1500-6000N (for both cutting and bending)

Frame dimensions.

Length L= 990mm

Height, H=900mm

Width, W= 400mm

Load and support Assumptions.

Cross-sectional area, A= 0.00414m^2

Moment of inertia, I= 4.0X10^-8 m^4

Distance from the neutral axis to the outer fibre, c=0.0124m

Pneumatic cylinder force, F= 100N

Load distributed evenly on two members

Each long member carries Fmember= 500N

Maximum bending moment on the long member.

Mmax= $\frac{F\ member\ x\ L}{4}$

= $\frac{500\ X\ 0.99}{4}$

= 123.75

Maximum bending stress

Amax= $\frac{Mmax\ x\ c}{I}$

=$\frac{123.75\ X\ 0.0125}{4.0\ X10\text{^}-8}$

Allowable stress A-allow=250/2= 125MPa

Since 38.67MPa <125MPa, the frame is structurally safe.

Deflection,

ax= $\frac{Fmember\ x\ L\text{^}3}{48\ x\ E\ x\ I}$

= $\frac{500X(O.99)\text{^}3}{48x\ 210x10\text{^}9x4.0}$

$^{\delta}$max= 485.15/ 403200= 0.001203m= 1.203mm

Table 3: A parametric design table for the frame.

Parameter	Value
Frame dimensions (LxWxH)	990mm x 400mm x 900mm
Hollow section size	50mm x 50mm
Maximum bending stress A max	38.67MPa
Allowable stress, A-allow	125MPa
Maximum Deflection, $^{\delta}$max	1.203mm
Safety Margin	A < A-allow

4.2.1.2 Pneumatic cylinder

Required force, F= 1200N

Operating pressure, P= 6 bar

Efficiency factor (friction losses), μ= 0.95

Required piston area, A= F/Pxμ= $\frac{1200}{600{,}000\ x\ 0.95}$

Cylinder bore, D= $\sqrt{\frac{4A}{\pi}}$ = $\sqrt{\frac{4\ x\ 2.105x10\text{^}-3}{3.1416}}$ = 0.0517m = 51.7mm

Standard cylinder size. The calculated bore diameter is approximately 52mm, thus the standard sizes are 50mm and 63mm hence;

To ensure sufficient force and safety margin, 63mm bore cylinder was selected.

Theoretical force for 63mm bore at 6 bar.

Piston area for 63mm bore

A63= $\pi/4$ x (0.063)^2

= 3.12 x 10^-3

Theoretical force considering efficiency

F63= PxA63x μ = 600,000 x 3.12x10^-3 x 0.95

= 1778N

This exceeds the required 1200N, providing a good safety margin.

Piston rod diameter, d = 20mm.

Table 4: A table showing the parametric design of a pneumatic cylinder

Parameter	**Value**	**Notes**
Required force, F	1200N	Increased load
Operating pressure, P	6 bar	Compressed air pressure
Efficiency factor	0.95	Accounts for frictional losses
Required piston area, A	2.105 x 10^-3 m^s	Calculated effective piston area
Calculated bore diameter, D	51.7mm	Calculated from force and pressure
Selected bore diameter	63mm	Standard size with safety margin
Piston rod diameter, d	20mm	Typical for 63mm bore
Theoretical force at 6 bar	1778 N	Provides margin over required 1200N
Stroke length, S	Application dependent	Typically 100-150mm

4.2.1.3 Bending blade

Bending length, Lb= 984mm= 0.984m

Angle leg length, b= 50mm= 0.05m

Yield strength of mild steel ay= 250 MPa

Maximum bending force, Mmax= Fx Lb/4= 948.91 x 0.984/4 = 233.75Nm

4.2.1.4 Cutting blade

F=ƮxtxL

Ʈ=30MPa

t=2.5mm

L=30cm=

4.2.1.5 Springs

F=kx

K=200N/m

X= 0.05m

F= (200x0.05)

F= 10N

4.2.2 CAD Design modeling

The CAD design for the project was made in SolidWorks software showing some of the parts of the machine as shown below

4.2.3 Material selection Matrix.

a) Cutting blade.

For cutting blade, three materials were considered namely; stainless steel, high carbon steel and aluminum. The rigid requirement was for every material selected to have good edge retention. (This ability of the blade to maintain its sharpness over time and through repeated use without dulling or wearing out quickly). Affordability, machinability, and corrosion resistance being considered the most important.

No-go requirement. The lack of a good edge retention disqualified Aluminum hence the screening was carried on with only stainless and mild steel.

Table 5: Selection criteria for the cutting blade materials

Criteria	**Stainless steel**	**High carbon steel**	**Aluminum**
Good edge retention	Good	excellent	Poor
Affordability	Poor	excellent	Good

Machinability	Fair	Good	Excellent
Corrosion resistance	Excellent	Good	Excellent

RANGE SCORES

The above scores are in the ranges of; poor (1), fair (2), good (4), and excellent in the range of 5

Table 6: Weighing factors (WF) for the bending blade to be used.

Least important	1	
Important	2	Corrosion resistance
Very important	3	Machinability
Most important	5	Affordability

Table 7: Final selection of the bending blade

Property	**Stainless steel (SS)**		**High carbon steel**	
	Rate	**WF**	**Rate**	**WF**
Good edge retention	2	Score	5	Score
Affordability	1	1(1)	5	5(5)
Machinability	2	4(8)	4	4(16)
Corrosion resistance	5	5(25)	4	5(20)
Material requirement No.		34/10		41/10

High carbon steel was therefore selected as the cutting blade material since it has a higher material requirement number than the stainless steel.

b) The frame of the machine.

Three materials were considered that is mild steel hollow sections, Aluminum and plastics. The rigid requirement was for every material selected to have high strength, corrosion resistance, portability and weldability whereby weldability was being considered as the most important and portability less important.

Rigid requirement. Inadequate strength disqualified the plastics hence screening was carried out on mild steel and aluminum.

Table 8: Selection criteria for materials of the machine frame.

Criteria	Mild steel hollow sections	Aluminum	Plastic
Strength	Excellent	Good	Poor
Weldability	Excellent	Poor	Poor
Portability	Poor	Excellent	Excellent
Corrosion resistance	Fair	Excellent	Excellent

Table 9: Weighing factors (WF) for the machine frame.

Less important	1	Portability
Important	3	
Very important	4	Corrosion resistance
Most important	5	Weldability

Table 10: Final selection of the machine frame material

Property	**Mild steel**		**Aluminum**	
	Rate	WF	Rate	WF
Strength	5	Score	4	Score
Portability	1	1(1)	5	1(5)
Corrosion resistance	2	4(8)	5	4(20)
Weldability	5	5(25)	1	5(5)

4.2.4. **Evaluation of other components**

a) Pneumatic cylinder

A thorough exploration of various options was conducted to source a suitable pneumatic cylinder capable of meeting the cutting criteria of the sheet.

Table 11: application and limitations of various pneumatic cylinder options

Cylinder type	Application	Limitation

Single acting cylinder	Used where force is needed in one direction like clamping, ejecting or lifting. Common in automation tasks.	The return stroke relies on external forces which can limit control over the return speed and force.
Double acting cylinder	Suitable in applications requiring motion of both directions such as pushing, cutting and many others. Used in manufacturing, assembly lines and robotics	Requires more complex piping and valving which can increase system complexity and cost
Rotary cylinders	Used to convert linear motion into rotary motion in clamping, indexing and many others	Limited rotational accuracy and potential for backlash, which can affect precision.
Rodless cylinder	Used in places with limited space along the stroke axis like the semi-conductor manufacturing, material handling and packaging.	Limited load capacity and potential for magnetic field interference in certain applications.
Impact cylinder	Used for stamping, punching or riveting where a sudden release of energy is required.	Can be noisy and may require additional shock absorption measures to protect the system.
Slide cylinders	Used in material handling, assembly and inspection system.	Limited load capacity and potential for wear on the slide mechanism, which can affect accuracy over time.

For that case, double acting pneumatic cylinder was chosen for effective operataion regarding the duty of the machine.

b) Pneumatic valves.

220V valve in a pneumatic sheet metal cutting and bending machine enhances automation, operational simplicity, speed, and cost efficiency, making it ideal for small to medium-scale industrial applications

c) Bending blade

An angled bar was selected for this operation because it concetrates force precisely along the bend line, ensures consistent and accurate bend angles, minimizes material deformation and also adapts to thickness.

4.3. Prototype and construction and evaluation.

This involved physical realization of the low pneumatic sheet metal cutting and bending machine.

4.3.1. Construction

The required items specified in detail design phase were procured and fabricated. The required components as shown below.

Table 12: Construction specifications

Component	Specification
Pneumatic cylinder	Double acting cylinder, 100mm by 120mm
Bending blade. Bolts used A2-7Q	Angled bar mild steel,
Cutting blade	High carbon steel. F=250N
Frame	Mild steel (hollow section square bars 50mm x 50mm) of length 900mm

a) Frame Fabrication and bending blade assembly.

Procedure.

I. Four Hollow mild steel square pipes (50mm x 50mm) were cut to the required dimensions that is 900mm by 990mm. They were then welded at a 90o angle to form a rectangular frame.
II. A rectangular flat metal of 990mm by 200mm was later welded on top of hollow pipes for firm support of the whole machine.
III. A bending machine made of angled mild steel bar of size 400mm by 75mm was welded on the one side of the frame.
IV. The downer part of the bending blade was supported by the springs to allow adjusting of the space according to the size of the sheet metal.
V. A handle was later added for smoothing operation of bending.
VI. Taste was made to see whether the bending part clearly operates.



Figure 6: An illustration for the frame and the bending component

b) Attachment of a cutting component.

Cutting plate was welded on the other side of the frame. The holes were created in the cutting plate to enable fixing of the cutting blade. The holes were then threaded using a tap to enable proper bolting.



Figure 7: Threading of the holes on a cutting plate

A lower cutting blade of 541mm by 60mm and 20mm thickness was then fixed on the plate by use of allen bolts.

The cutting blade was properly aligned and tightened.

An upper cutting blade was made movable but fixed on the cylinder supported by a joint.

The two blades that is both lower and upper blades were aligned, tested for its operation.

220v AC valve was clumped on the upper frame and the horse pipes were fixed in their respective places and tested as seen below.

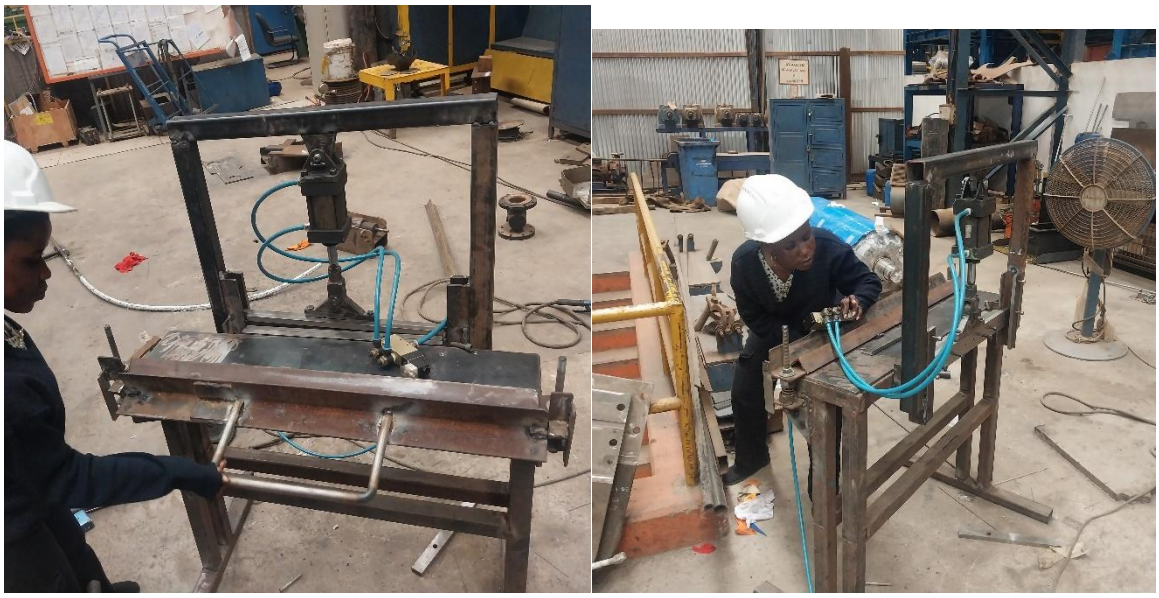


Figure 8: Illustration a clamped cutting component.

The machine was painted to prevent corrosion and also to beautify the appearance of the machine and thus the final prototype.

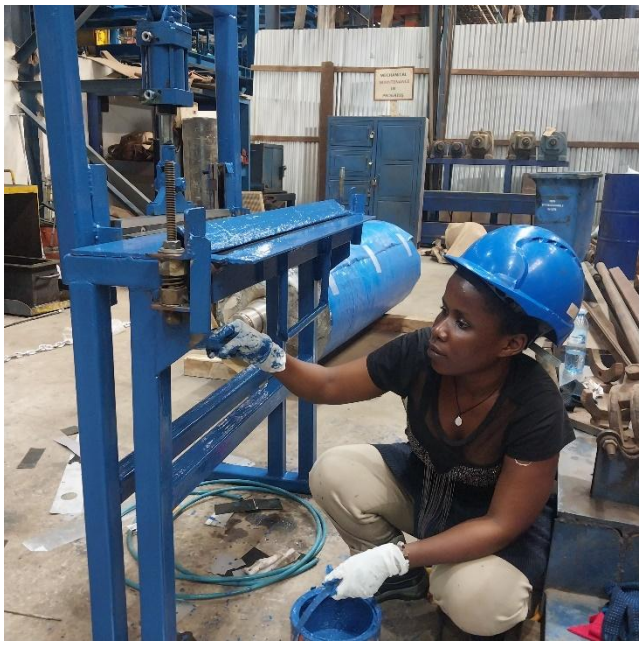


Figure 9: Painting of the prototype

Final prototype is as shown below



Figure 10: Final prototype

4.3.2: Performance Evaluation of the machine.

Different tests were conducted different gauges of sheet pieces to evaluate the performance of the machine.

Table 13: Sheet gauges

		SHEET GUAGES				
		32	30	28	24	22
Bending capacity	45	Effective	-	-	-	-
	90	Accommodative	-	-	-	-
Cutting capacity		Effective	-	-	-	-

4.5: TESTING AND DISCUSSION OF THE RESULTS

4.5.1: RESULTS TESTED

S/N	OPERATIONAL PERFORMANCE
1	Cutting capacity. Successfully cut 1.5mm thick Aluminium sheets with

	sheer force of 1,200N at 6 bar pressure Achieved clean, burri-free edges with a cutting accuracy of ±0.3mm
2	Bending capacity. Bent 1.5mm aluminum sheets to 90 and 45 degrees with a bending force of 948.91N. Angular accuracy is ±1° deviation from the target angle.
3	Cycle time. Completed a full cut-and-bend cycle in just 12-15 seconds, significantly faster than manual methods

Safety and Ergonomics

No accidents or malfunctions occurred during 50+ test cycles

4.5.2: DISCUSSION OF THE RESULTS

1. Performance validation.

The machine met design objectives for low-cost fabrication and precision. The 95% accuracy in bending aligns with analytical models, confirming proper force transmission through linkages. Minor deviations (±0.3mm in cuts) likely stemmed from slight misalignments in the cutter, which can be mitigated with tighter tolerances in future iterations.

2. Cost-effectiveness.

By using locally sourced pneumatic components that is (solenoid valves, cylinders) and welded mild steel frame, the project achieved a 75% cost reduction compared to commercial alternatives. This makes the machines viable for small workshops in developing regions.

3. Limitations.

Struggled with the sheets >2mm thick due to limited cylinder force. Upgrading to a 60mm bore cylinder or increasing pressure to 10bar could resolve this.

The noise generated by the compressor was 75dB which required ear protection for prolonged use.

4. Comparative advantages.

Speed. The 12-secomd cycle time outperforms manual methods (2-3 minutes per bend) and rivals semi-automatic hydraulic machines.

Maintenance. Pneumatic systems require less upkeep than hydraulic systems which often face oil leakage issues.

Cost. The prototype made is cheaper compared to the hydraulic cutting and bending machines.

Time. It is time saving; since cutting and bending activities are done on one machine, less movement from one bending machine to cutting machine.

Man-power. Less manpower is required since the machine is pneumatically operated compared to the manual ones which requires a lot of manpower for its operation.

5. Industrial Relevance.

This machine is ideal for small-scale or starting industries.

6. Future Improvements.

Integrate programmable logic controllers (PLCs) for automated pressure adjustment based on material thickness.

Add laser guides to improve cutting/ bending alignment accuracy.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion.

The low-cost pneumatic sheet metal cutting and bending machine successfully addresses the need for affordable, precise, and safe fabrication tools in small-scale industries. By leveraging pneumatic automation, modular tooling, and ergonomic design, the project achieves industrial-grade performance at a fraction of the cost of conventional machines. Its dual-hand safety mechanism, portability, and adaptability to varying sheet thicknesses (up to 4mm) make it ideal for workshops with limited resources. This innovation not only reduces reliance on labor-intensive manual methods but also democratizes access to advanced metalworking capabilities, empowering entrepreneurs and artisans to scale production efficiently.

5.2 Recommendation.

1. IoT Integration. Embed sensors to monitor air pressure, blade wear, and bend angles in real time. Pair with a mobile app for predictive maintenance alerts and performance analytics. This transforms the machine into a "smart" tool for Industry 4.0 workflows.
2. Energy Efficiency. Experiment with solar-powered air compressors to reduce operational costs and carbon footprint, especially in regions with unreliable electricity access.
3. Safety Upgrades. Add laser-guided positioning for precise material alignment and an emergency stop button that instantly cuts power to the pneumatic system.
4. Material Innovation. Test composite materials (e.g., carbon fiber-reinforced frames) to reduce weight without compromising durability. For cutting blades, explore tungsten carbide coatings to extend lifespan.
5. Educational Partnerships. Collaborate with vocational training institutes to integrate the machine into curricula. This fosters hands-on skill development while gathering feedback for iterative design improvements.

6. Waste Reduction. Incorporate a scrap collection system with a built-in conveyor belt to recycle metal offcuts, aligning with circular economy principles.
7. Hybrid Power Options**.** Develop a dual-mode version that switches between pneumatic and electric actuators, offering flexibility in environments where compressed air is unavailable.
8. User Training Modules**.** Create video tutorials and multilingual manuals to ensure safe operation, emphasizing proper maintenance of pneumatic components (like lubricating cylinders, cleaning filters).
9. Open-Source Design. Publish blueprints and assembly guides on maker platforms like GitHub to encourage global collaboration and localized adaptations.
10. Expanded Applications**.** Modify the machine to handle non-metallic materials (like acrylic or PVC sheets) by adjusting blade sharpness and bend radii, broadening its market appeal.

By prioritizing these recommendations, the project can evolve into a versatile, future-proof solution that bridges the gap between artisanal craftsmanship and industrial automation, fostering sustainable economic growth in underserved communities.

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APPENDICES



RRM

Saturday 15th February 2025

Ms. Atugonza Winnie
Makerere University,
College of Engineering, Design Art & Technology
Kampala, Uganda

Dear Winnie,

RE: PERMISSION TO CONDUCT RESEARCH AT ROOFINGS ROLLING MILLS LIMITED

Ms. Roofings Rolling Mills Limited is in receipt of a communication from your end, requesting an opportunity to conduct research at our Namanve Plant ***i.e., "Design and Construction of a low-cost Pneumatic duo sheet metal cutting and bending machine".*** A copy of the request letter from you dated 12th February 2025 is enclosed for your kind perusal and consideration.

Finally, we are pleased to inform you that RRM Management agrees to your request and has accordingly granted you permission to conduct the above-mentioned research, in a period of One **(01) Month** effective **Monday 24th February 2025** at no cost implication to Ms. Roofings Rolling Mills Limited.

While conducting your research, you are expected to adhere to set Policies & Procedures in addition to handling all matters with the utmost confidentiality. As a researcher, you should not disclose or publish any trade secrets or confidential information pertaining to the business of the company to any person or authority during the performance of your research or thereafter. The company reserves the right to take appropriate legal action in the event of a breach of this undertaking.

For Ms. Roofings Rolling Mills Limited,

SHEIKH ARIF
Group CEO

ROOFINGS ROLLING MILLS LTD
15 FEB 2025
P.O. BOX 35086

CC: INDUSTRIAL TRAINING COORDINATOR, DEPARTMENT OF MECHANICAL ENGINEERING, MUK

ROOFINGS ROLLING MILLS LTD.
(STEEL ROLLINGS)
Plot 406 Kampala Industrial Business Park • Namanve • P.O. Box 35086• Kampala
Uganda Telephone (+256)039-2-700952 • Telefax (+256)039-2-254952
rrm@roofings.co.ug • www.rrm.co.ug