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DEVELOPMENT OF SHEET METAL BENDING MACHINE

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ABSTACT
A metal bending machine for bending 8 feet wide sheet metal into various curves, angles and shapes was designed and constructed. The clamping and the bending beam of the bending machine were made of mild steel plate. To improve the efficiency of the machine a counter weight of 67 kg was bolted to the bending beam. The dimension of the bending plate is 2.4 × 0.24 m × 0.015 m. The application of mechanical fastener and arc welding were used in the joining of the parts. The welded parts were grinded, sand blasted and painted to enhance its aesthetics. The capacity of the bending machine is 2.4 m sheet metal of 3 mm thickness. The angular deformation of the sheet metal from experimentation is inversely proportional to the metal sheet thickness.

Keyword: Bending, Deformation, Machine, Shapes, Sheet, Thickness

INTRODUCTION

Consumer durable products made entirely or in part from bent sheet metal are becoming more and more in demand. These products range from tools to hinges and automobile parts (Gwangwava *et al.*, 2013 and Cloutier, 2000). The processes in the fabrication of metal sheet can be from deep drawing, stamping, forming, and hydro forming to a high energy rate to form a desired shape (Cloutier, 2000). A piece of sheet metal can be bent at an angle and given the desired shape by applying force to it during the bending process. (Manar, 2013). It is a process by which material is plastically deformed and changed its shape. The material experiences stress higher than its yield strength but lower than its ultimate tensile strength (Anand *et al*, 2018). Sheet metal can be bent into different shapes like the V-shape, U-shape, or channel shape along a straight axis by bending operation. Mahesh and Amol (2015) stated the processes of bending, which turns a straight length into a curved length, and roller forming, which is a continuous bending operation that involves passing a long strip of metal through a typical roller that is adjusted until the desired curvature shape occurs. Material, loading condition, and sheet metal thickness are all affected by how the metal bends.

The impotence of person to bend metals into desired shapes and angles had necessitated the need to produce sheet metal bending machines for quality products to reduce each and every work of humans in bending a sheet metal. In mechanical industry sheet bending is an essential part of all manufacturing. All materials are elastic in nature, and deforms when exposed to an external force. As the body deforms, tensile and compressive stress was set up in its composition causing severe deformation of the material. Bending of sheet metal can be carried out in stamping dies that was designed for forming operations. Many of the bending operations are made in press brake. Press brakes may be mechanical or hydraulic in operation (Raval and Raymond, 2013).

Bending machines are used for bending various length and thickness of sheet metal depending on the capacity of the machine. Commonly used equipment for bending sheet metal include: brake presses, box and pan brakes. A particular product made from bending processes are boxes such as electrical enclosures and rectangular ductwork. (Groover, 2010).

Bending operations are occasionally performed on heated parts, because heat treatment increases the ductility of the metal. Sheet metal can sometimes be formed in a high-pressure environment, which is another way to make it more bendable (Crill and George, 2014). Bending machine is widely used in various industrial operations such as bending a tube to make coil or sheet metal to make certain shape such as V shape. There are many types of bending machines that can be found in many industries.

Types of Sheet Metal Bending Machine

The market is full of many kinds of sheet metal bending machines with different configurations. These tools can be found in small-scale workshops or tool rooms on building sites for low-volume activities, or they can be more basic types utilized in highly developed industrial processes. Common types of metal forming machinery include shearing, press braking, bending roller, and power press.
One essential piece of sheet bending machine equipment for bending metal sheets and plates into certain shapes is the press brake. A variety of press brake types are used by industries to bend metal. These include the widely used mechanical, hydraulic, and pneumatic press brake versions. Through the press brakes, application of various dies different metal forming jobs like curling, angled shaping, bending, bottoming, seaming and hemming can be done (Shigley and Mischke, 2010).

Universal Bending Machine

This type of sheet metal bending machine is made up of several separate brakes called fingers. Finger blades can be detached systematically to achieve different type of bends. Universal bending machine is otherwise known as box and pan bending machine. Most of the box forming were achieved using the box bending machine which is different from damp folder in designing of the upper blade. The machine is operated by oscillating the front portion of the bed, which has the bottom blade on a hinged center with the top blade. The machine is designed to bend metal sheets into various shapes, making it appropriate for both new and repair work (Pratik, 2014).

Clamp Folder Machine

Clamp folder is also called angle bender. The operation of the machine is very similar to that of universal bending machine. The two components of a clamp holder are the clamp to which its blade is fixed to and the bed that holds the sheet metal. It is also operated by a hand tower attached to the end of the machine which is typically used for sheet metal bending up to 16mm thick. Moreover, it must be noted that to produce a fine and neat bend of sheet metal, the metal bending blade should be straight, smooth, fairly sharp, and evenly distribute the force along the length of the bend.

Edge Folder

An edge folding machine is utilized to bend edges on metal sheets in order to create hooks for grooves and seams for inserting wire. It can also be used in the production of small flange, typically, the machine is employed exclusively for mild steel with a thickness of 0.8mm.

Open end or bending machine

This machine is only appropriate for bending operations that are single. The eccentric shaft with handles at both ends is what raises the clamping beam and top blade. These components helps in lifting and bending blade up and down. Some designs make provision for counter balance weight attachment for easy lifting up and down of bending beam. The blade in this specific bending machine has a maximum length of 1828.8mm (6ft).). The highest gauge that can be bent is 16mm. The following are the example and types of bending machine; automatic bending machine, hydraulic benders and long bending machine (Pratik, 2014).

Shape Rolling Machine

Thin is the type of bending machine that roll a sheet metal by bending it continually along a straight axis. The original shape of the sheet changes as it moves through a set of rollers. The shape rolling machine is highly beneficial in the manufacturing sector for creating components such as inner and outer panels and stiffeners in the automotive and agricultural industries. (Bello (2013). Sheet metal can be formed into cylindrical and conical shapes to make stoves, cylinders (such as flue pipe, water pipes), curved machine parts, buckets, bins, gear box covers, mud guards, poultry drinkers and feeders, feed mixers, as well as in food cans and civil engineering projects.

Bending Technique

The bending process alters the configurations of sheet metal by applying a force that exceeds the material's yield point while remaining below its ultimate tensile strength. In the course of bending, the metal experiences stretching along its outer radius and compression along its inner radius. The midpoint between these two radii is referred to as the neutral axis, serving as the reference point for subsequent analysis.

Tensile stress is the stress state caused by an applied load that tends to elongate the material along the axis of the applied load, i.e., the stress caused by pulling the material. When the segment experiences two equal and opposing forces that cause the materials to elongate, the resulting stress is referred to as the tensile stress. The corresponding deformation is known as tensile strain. Therefore, due to the tensile stress, the cross-sectional area of the material diminishes.

The amount of force necessary to execute a bend is significantly influenced by the bend radius and the particular metal bending technique employed, as the mechanics of each method differ accordingly. Adequate lubrication is crucial for managing the deformation forces, which in turn impacts the overall process. (Spots, 1991).

There is a point of the material containing fibers that do not undergo any extension or compression, and this are not subjected to any tensile or compressive stress. This layer which remains unaltered during bending process is called the neutral surface of the material. The type of bending forces applicable in bending of any metal sheet is an evenly distributed force which result in what is known as ordinary bending while that of coplanar forces is called 'pure bending' (Suchy, 2006).

Bending Length Calculation

The required flat length of the sheet stock, which will yield the specified dimensions of the finished bent parts, was determined by incorporating the bend allowance. The bend allowance (BA) is the length of the arc of the neutral line between the tangent points of a bend in any material (Aniruddha *et al.*, 2015)

According to Rao, (1998) Bend allowance is determined with a formula,

$$B = \alpha(R + Kt)\mathrm{B}$$

Where:

α is the bend angle (radians),

R is the inside radius of the bend (mm),

K is the location of neutral axis from bottom surface, K is 0.33 when R < 2 t; 0.50 when R > 2 t and t is the sheet metal thickness (mm).

The pictorial view of where the bending takes place and the relative effects are shown in Figure 1 and 2. Figure 1 shows a single bend in a metal part while Figure 2 shows the flat form of the sheet metal.

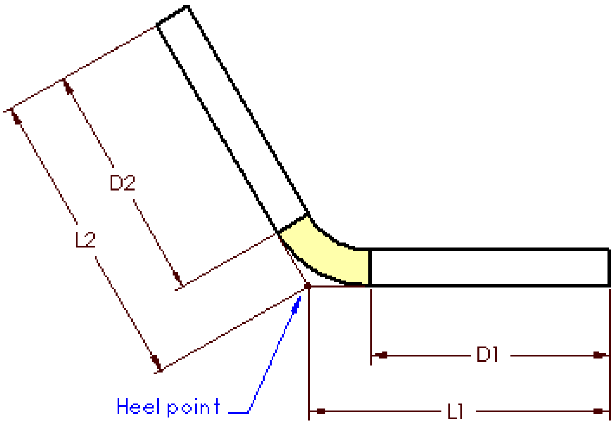

Figure 1: A single bend in a metal part (Rao, 1998)

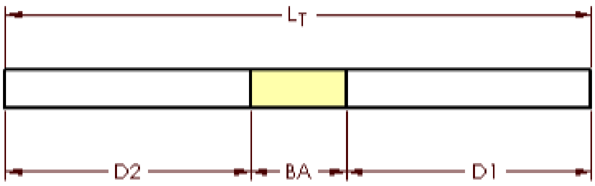

Figure 2: The flat form of the sheet metal

MATERIALS AND METHODS

This metal sheet bending machine consists of two uprights on which a strong (rigid) rectangular bar is placed to prevent deflection of the bar. The rectangular bar has an arrangement on it which incorporates the stake and the bending bar. The extension of the bending bar handles outwardly from the bending machine and the counter balance weight attached to the bending stake enhances easy and smooth raising and lowering of the bending stake for bending the metal sheet into different desirable angles or curves. Other parts of the machine include; helical spring fastened into the cam follower with the clamping beam for the adjustment of the blade to align with the plate rest, the operation principle of this machine involves the lifting of the top part of the machine where the bending blade is incorporated by applying a downward force to the cam handle which in turn rotate the cam round its eccentric parts. The rotational motion of the cam is whereby translated to the vertical linear motion of the bending stake on top of the rectangular bar by the lifting action of the internally threaded shaft on the rings. Having provided the desire clearance between the bending plate and the rectangular bar through which the specimen (metal) to be bent is placed in position. The top component returns to its original position and grips the work piece by releasing the cam lever.

The bending handle is lifted upwardly so that the flat metal plate of the handle bent the sheet metal to the required shape. The sheet metal is then removed following the completion of the bending process by lowering the cam lever again which in turn lift up the upper frame of the machine and the sheet metal is removed. The working drawing of the bending machine is shown Figure 3.

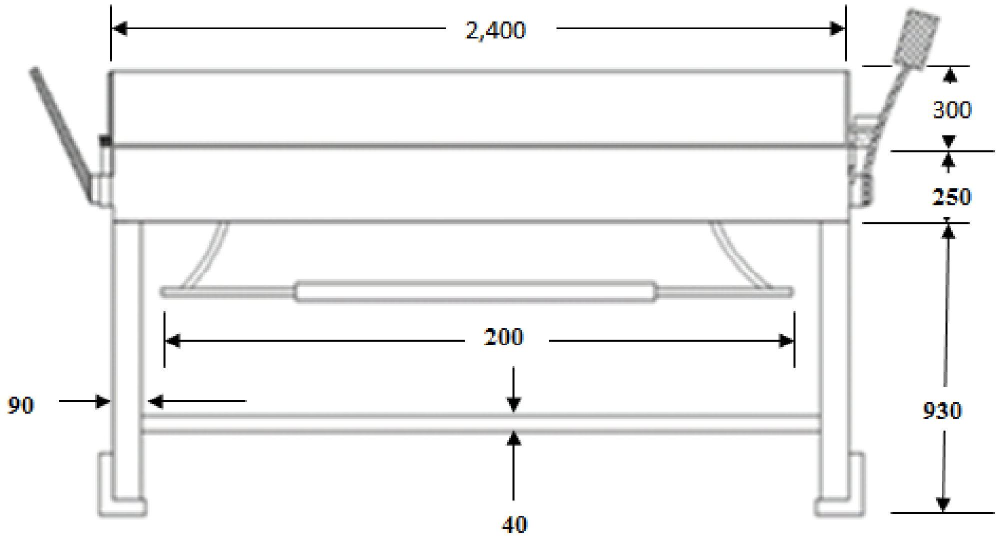

Figure 3: working drawing of the bending machine

Design Analysis

The material selection for the construction of the bending machine was determined factors such as: cost, availability, the mechanical and the metallurgical properties of the materials. The parts of the machine are the pillar stand, clamping beam, bending handle and the counter weight.

Maximum Bending Force

The required force for bending as sheet metal, depends on the strength, thickness, and length of the sheet metal. The maximum bending force was estimated by using equation (1) as given by Gwangwava *et al.,* (2013).

$$F = \frac{K_{bf}(T_S)Lt^2}{D} \quad (1)$$

where:

K_{bf} is the K-Factor = 0.33

T_S is the Tensile strength of sheet metal (Mild steel) = 248 MPa

L is the length of sheet metal = 2.400 m

t is the maximum thickness of the sheet metal = 3 mm; and

D is the Clearance between folding beam and clamping beam = 3 mm.

The maximum bending force was calculated to be:

$$F = \frac{0.33 \times 248 \times 2400. \times 3^2}{3} = 589.25 \text{ kN}$$

Clamping Beam Design

The clamping beam is utilized at both ends of the machine to apply force that secures the sheet metal onto the folding bed. It is 50% of the required folding force (Gwangwava *et al.,* 2013). The clamping force is estimated using equation (2) as given by Gwangwava *et al.,* (2013).

Clamping force = 0.5 x folding force (2)

Clamping force = 0.5 x 589.25 kN

= 294.62 kN

The clamping beam is designed and bolted to the two vertical frames, which are linked to a clamping mechanism. The clamping mechanisms are positioned on each side of the clamping beam. The load is distributed evenly across both sides of the clamping mechanism, resulting in each side bearing an amount equal to half of the total clamping force that is 147.31 kN. According to the Society of Automotive Engineers (SAE), grade 4 material with no head marking and proof strength of 289.25 kN/mm^2 was selected and the allowable stress levels was 75% of proof strength.

The allowable stress is:

S_a = 0.75 x proof strength

S_a = 0.75 x 289.25 kN/mm^2

S_a = 216.94 N/mm^2

The force on each side of the clamping mechanism is 147.31 kN

The required tensile area to which the force should act is:

$$A_t = \frac{Load}{\text{Sa}} \quad (3)$$

$$A_t = \frac{147310N}{216.94\text{N/mm}^2}$$

$$A_t = 679 \text{ mm}^2$$

Tensile stress area of 679 mm^2 is required

Therefore, the thickness of the column for the clamping mechanism should be 16 mm X 42 mm mild steel plate.

The weight of the bending beam

The front view of the bending beam is shown in figure 1

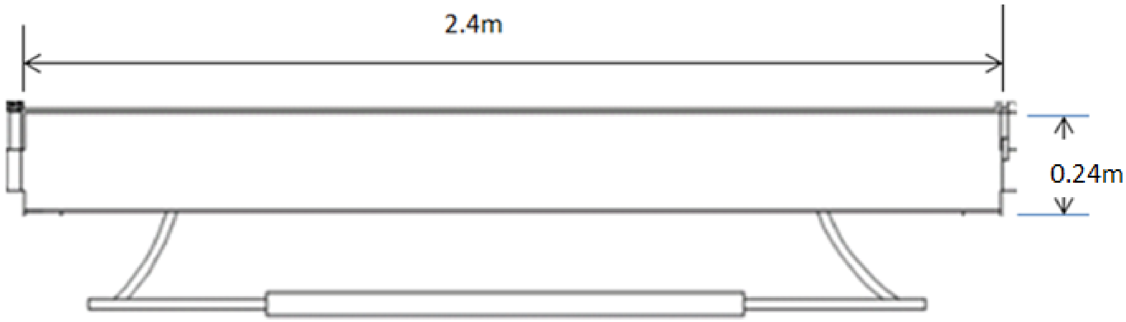

Figure 1: Bending Beam Front View

The weight of the bending beam was calculated using the equation (4) as given by (Gwangwava *et al.*, 2013).

$$W = A_s \times t \quad (4)$$

where:

W is the weight of folding beam

A_s is the surface area density, and

t is the thickness

W = 2.4 X 0.24 X 77 X t kN = 44.35t (kN)

The beam is supported at both ends, with the additional force, which encompasses its weight, being the maximum necessary bending force of 589.25 kN applied uniformly along the entire length of the beam. The total forces acting on the beam =589.25 kN + 44.35t (kN)

$$\text{Force acting per unit length} = \frac{\text{Total force acting on the beam}}{\text{Length of the beam}} \quad (5)$$

Force acting per unit length = $\frac{589.25 + 44.35t\,kN}{2.4}$ = (245.52 + 18.48t) kN

Total force acting on the beam = (245.52 + 18.48t) kN

Reaction force at the beam supports:

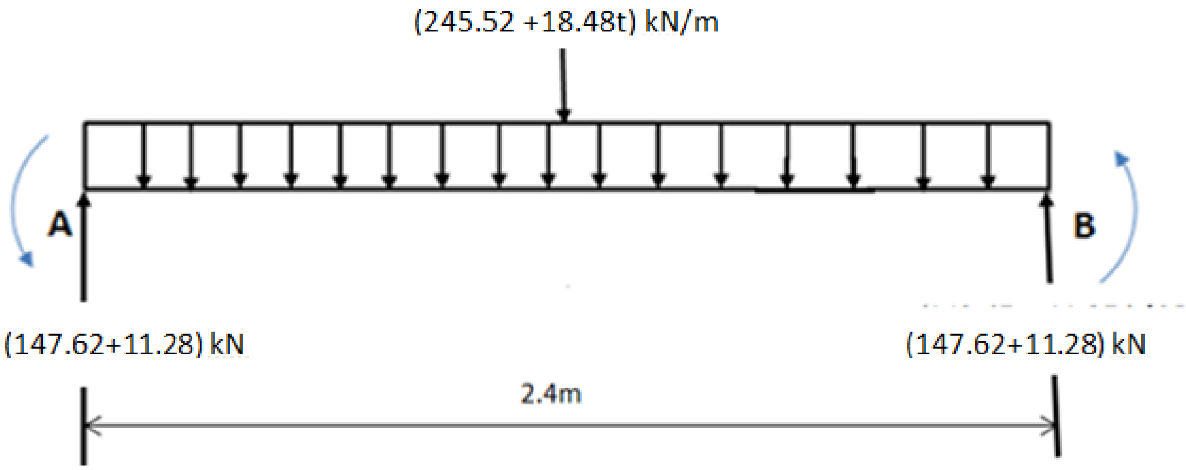

Figure 2: Loading on the Bending Beam

(147.62+11.28) kN (147.62+11.28) kN

Reaction at each support = $\frac{\text{Total force acting on the beam}}{2}$

Reaction at each support = $\frac{294.35.35 + 22.55t\,kN}{2}$

Reaction at each support = (147.62 + 11.28t) kN

Taking moments and resolving forces at determined points along the folding beam using equation (5) as given by Varma, (2017) and Ejiko et. al., 2021.

$$\sum Ma = R_{ax} - \frac{Wx}{2} = 0 \qquad (6)$$

where:

$\sum M_a$ is the summation of moment about point A.

R_a is the reaction at point A,

x is the perpendicular distance to the point of action of the force, and

W is the total weight that is acting on the bending machine.

$$\sum M_a = (147.62 + 11.28t)2.4 - (245.52 + 18.48t)1.2 = 0$$

t = -12.06

Considering a safety factor of 4 and an allowable stress of 350 MPa, the value of t is determined to be as follows.

$$t = \frac{-12.06 \times 4}{350} = -0.015 \text{ or } 0.015$$

The thickness of the folding beam is 15 mm.

Counter weight

Counter weight for easy lifting of the bending beam was welded to one end of the bending beam. According to IHSA (2018) the design factor of counter weight for beams must be in ratio 4 to 1. The counter weight was derived using equation 6 as giving in IHSA (2018), Figure 3 shows the schematic diagram of the counter weight

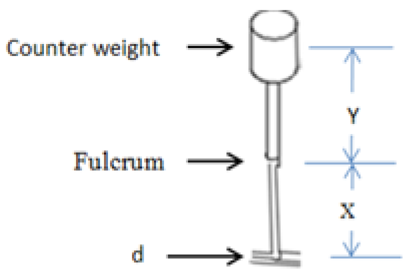

Figure 3: Schematic diagram of the counter weight

$$\frac{(X \times F)}{Y} \times 4 = W \quad (7)$$

where:

X is the distance of the bending beam from the fulcrum to the suspension handle (400 mm),

Y is the distance of the bending beam from the fulcrum to the center of the counterweights (550 mm).

W is the required counter weight.

F is the applied load (589.25 kN)

The couter weight was calculated to be:

$$\frac{(150 \times 599.92)}{550} \times 4 = 654.5 \text{ kN} = 66.71 \text{ kg}$$

Deformation of the Pillar Support due to Force of the Clamping beam acting on it

When a sufficient load is applied to a metal or other structural material, it will cause the material to change shape. Due to the force of the clamping beam acting on the pillar support, the deformation of the pillar support was derived using equation 7 as given by Padghan *et al.*, (2015)

$$\delta = \frac{WL^3}{48EI} \tag{8}$$

Where:

δ is the deformation of the flat bar,

E is the modulus of elasticity, (196×10^3 N/mm^2)

I is the Moment of Inertia ($\frac{bh^3}{12}$) (Ejiko et. al., 2022; Ejiko and Akinola, 2018)

b is the width of the plate,

h is the thickness of the plate

L is the length

The deformation of the plate was computed as:

$$\delta = \frac{599.91 \times 2400^3 \times 12}{48 \times 196 \times 10^3 \times 180 \times 18^3}$$

$= 10.08$ mm

Figure 4 shows the isometric view of the 8 feet metal sheet bending machine, while Figure 4 shows the orthographic views of the bending machine which represent the three dimensional side of the machine, in which the three axes appear equally foreshortened and the angle between any two of them is 120 degrees. (Krikke, 2000).

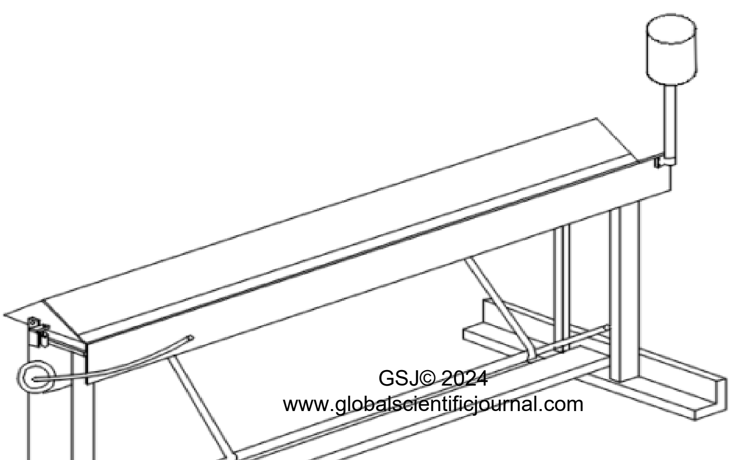

Figure 4: Isometric view of the bending machine

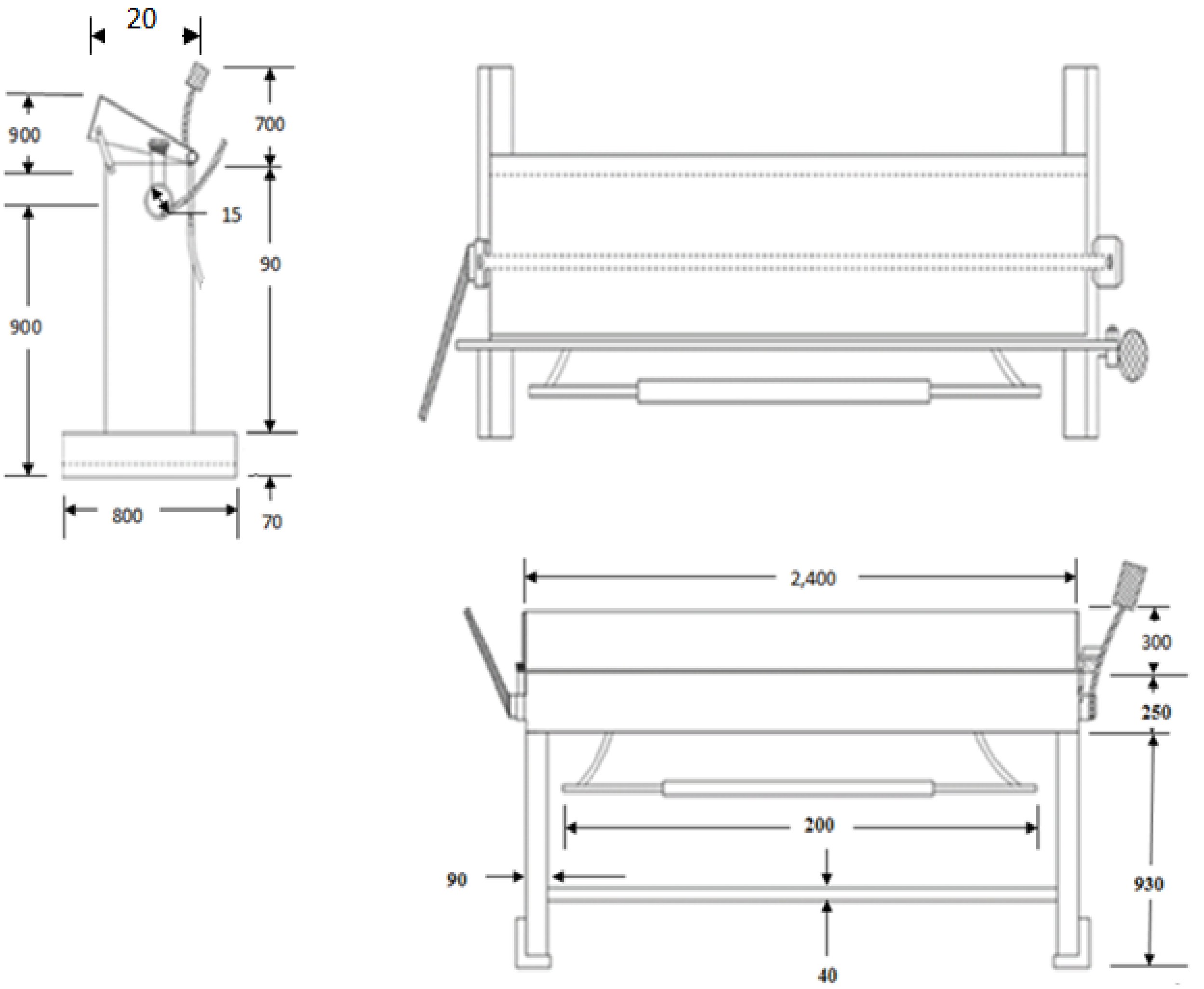

Figure 5: Orthographc view of the bending machine

RESULT AND DISCUSSION

The experimental application of the developed machine is capture in plate 1 and 2, showing the angular deformation of various sheet metals with reference to their thickness. At the minimum thickness of the metal sheet (0.5 mm) produces the maximum angular deformation (90^o), and the maximum thickness of the metal sheet (3 mm) produced the minimum angular deformation (50^o). The results showed that the angular deformation is inversely proportional to the material thickness i.e., the smaller the thickness of the metal sheet the larger the angular deformation. Figure 6 shows the graphical illustration of the deformation of bent sheet metal. This implies that the thicker the material the less deformation experienced in order to produce homogenous deformation for varieties of materials, the forces applied should be increased with respect to thickness of the material.

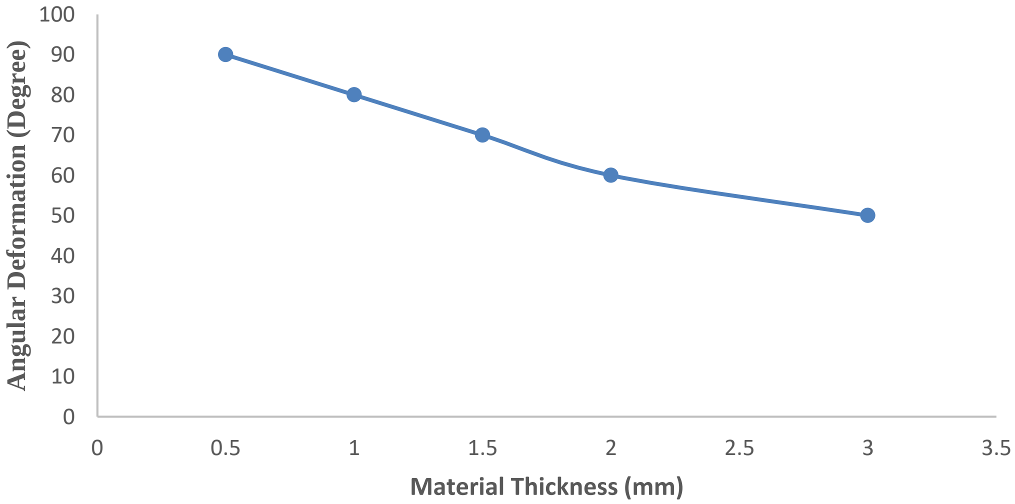

Figure 6: Graph of angular deformation versus the sheet metal thickness

Plate 1: Testing of the Machine

Plate 2: Tested Materials

CONCLUSION AND RECOMMENDATION

Conclusion

A metal bending machine for bending 8 feet wide sheet metal into various shapes was developed. The bending machine's beams were constructed from mild steel plate. To enhance its efficiency by minimizing the necessary bending force, a counterweight weighing 67 kg was affixed to the bending beam of the machine. The bending beam is of 2.4 × 0.24 × 0.015 m.

Recommendation

Improvement on the developed machine will require calibration to establish an accurate sheet metal bending angle. U-bar should be used in place of flat bar in the machine construction for better rigidity, strength and output.

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