

# A Brief Overview of Bending Operation in Sheet Metal Forming



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**Abstract** Bending operation in sheet metal forming has been extensively used in manufacturing technology for mass production especially in automotive industry as one of the tools for shaping into a desired shape and geometry, therefore to keep abreast some of the trends in bending operation. In this short overview paper, different types of bending techniques were exploited and presented varying from old age to modern age of bending operation. Theory of bending was also discussed extensively in this paper.

**Keywords** Bending operation · Manufacturing technology · Shape · Sheet metal forming

## 1 Introduction

Researchers have shown that sheet metal forming has made major and crucial contributions in many industries especially automotive and transportation companies in terms of development [1, 2]. The most common metal sheet forming process being the bending process, also known as metalworking, produces a V shaped (channel or U shape) shape along the axis of a material by applying a force to a metal sheet causing it to bend into the desired shape. This is done in ductile materials. Such materials are used in brake presses, pan brakes and specialized machine processes [3]. Wipe bending needs the sheet to be held against the die by using a pressure pad, causing the sheet to bend against the radius of the edge. There are two main quality considerations when doing the sheet metal bending process which include but are not limited to formability and dimension. Consistency is also mandatory which is minimizing the variations in dimensions which is a key requirement within mass production [4]. In this paper, the recent developments within the manufacturing space particularly with the focus on bending operations are analysed.

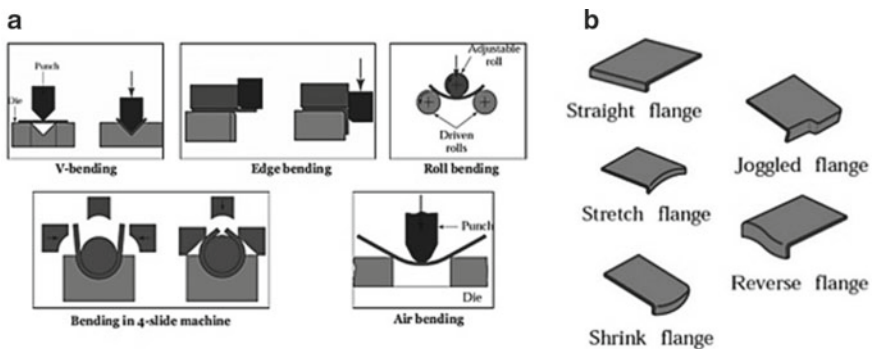
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It is a known fact that advancement of the fourth industrial revolution will bring about changes in all industries and technological processes. Metal forming, as a technological process, will also be impacted by this rapid change. These changes include but are not limited to the improvement of production productivity, increased production rate of completed products, reducing technological difficulties between the adjusting equipment and the die and also a reduction in the time it takes to set up the die. These improvements will be brought about by an intelligent press system mainly consisting of four basic elements: control, identification, prediction and monitoring [2]. Bending along a straight line or path is one of the most common types of processes in sheet metal forming. Bending of metal sheets can be done in a variety of processes such as wiping, flanging or folding using specialist machinery, bending the metal in a die or bending the sheet in a die that has a radius.

### 1.1 Bending and Forming Operations

Bending operation is a technique that involves plastic deformation of materials especially metals around a linear axis, known as the bending axis with little or no change in the surface area [5]. This results in the uniform straining of the sheet metal. Simply put, bending occurs when a portion of the part is deformed along the linear axis until such a desired or undesired bending occurs. This bending process does not only occur in a straight line or a linear axis but along curved lines and paths as well. An important observation needs to be noted about the characteristics of the metal that occurs during bending operations. It was established that tensile strength becomes lower towards the middle of the sheet metal thickness and zero at the neutral axis, but there was increase in compressive stress from the neutral axis towards the middle of the bend. It is cogent to establish that in bending operation, there is no cutting of metal sheet but there is a change in the contour of the workpiece to get the desired product. Bending operation can be categorized into various types as depicted in Fig. 1a, which are (a)



**Fig. 1** a Types of bending and b types of flange

V bending, (b) stretch forming, (c) edge bending, (c) beading, (d) roll bending, (e) flanging, (f) press break forming, (g) dimpling, (h) roll forming, (i) bulging, (j) air Bending and (k) tube forming [6]. When bending occurs in a curved path, flanging or stretching occurs in the metal sheet. Some of the flanges that occurred are illustrated in Fig. 1b. When flanging occurs in a bending operation it is classified into two forms namely shrinkage flanges and stretching flanges. Shrinkage flanges imply that the sheet metal is compressed or squeezed during the metal forming process and stretched flanges imply that the metal is stretched and subsequently thinned during its forming process. In order for a metal sheet to be considered as undergone a bending process, the cross-sectional area of the bent or flanged metal sheet must have the same thickness as the rest of the sheet in which it was made [6].

## 1.2 Bend Radius

Two important factors considerably affect bending of sheet metals. They are the bend radius and the size of the bend angle. At large bend angle, many materials can be bent to this degree without a great degree of difficulty since a little difference exists in the flat material and the one that has been formed. The bending radius greatly affects the desired bending results. The bending size depends on the thickness of the material and the hardness of the material. The smallest radius attained by bending can be expressed in Eq. 1 [7].

$$BR_{\min} = kt \quad (1)$$

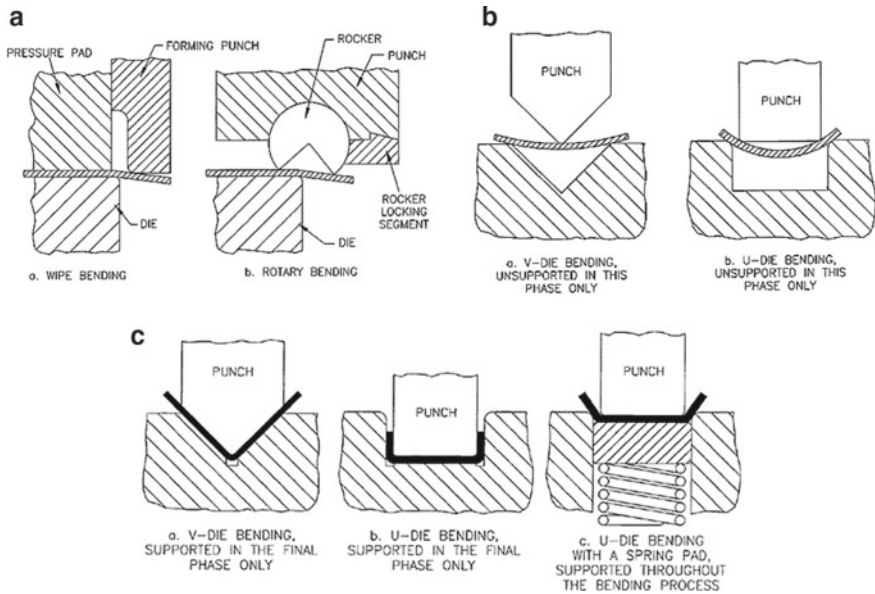
where  $BR_{\min}$  is the minimum bending radius,  $t$  is the thickness of the material and  $k$  is the coefficient of the minimum radius for a given material.

## 1.3 Types of Bending Operations

Different types of manufacturing processes can accomplish different bending operations. There are supported as shown in Fig. 2a and unsupported bending operations as shown in Fig. 2b.

Unsupported bending can be described as the process in which stretching a sheet metal stretches in a retained die. V-die and U-die can be regarded as unsupported bending at their initial stages. As shown in Fig. 2b, as the bending process continues, and the material is pulled down into the recess, all the way down, the bending becomes supported, as shown in Fig. 2c [7].

Complex geometric shapes have helped humanity save space and be able to design structures that can be observed in cars, ships, airplanes and many other applications



**Fig. 2** a Supported and partially supported bending [7]. b Unsupported bending [7]. c Supported bending [7]

[8]. One of these shapes is bending, and many structures have bending geometries in their designs and this structural shape can save space and give beautiful designs but also can render the structures of the material weaker than their initial structure [9]. The material may crack, tire or buckle depending on the nature of the material used. Bending of materials can increase its economic value and save space for specific applications which require it. The process is used to manufacture structures such as flanges, clutches and brake pressure levers, and I-beams for building towers, and the applications are limitless but they increase the economic value of the starting workpiece since its being appropriately shaped for the required application [8].

### 1.4 Theory of Bending

The workpiece is plastically deformed within the plastics deformation region of the stress–strain graph of the material it is made from. The reduction in the radius of the workpiece is limited by the ductility of the material, usually materials that are categorized as having a high ductility usually possess high radius of curvature and vice versa. One of the most important bending parameters in design is the bending allowance, which models the failure point in the radius where the workpiece may start to crack under bending, and to help prevent it [10, 11], the principle of bending allowance,  $L_b$  as shown in Eq. 2, is adopted.

$$L_b = \alpha (R + kt) \tag{2}$$

where  $\alpha$  is the bend angle,  $R$  is the radius, and  $t$  is the thickness.

$k$  is a constant which is obtained from the following details:

K—Constant		
Radius	$R < 2t$	$R > 2t$
$K$ value	0.3333	0.5

The material particles in a bent workpiece experience tensile forces of the out surface and compressive forces in the inner surface. This forces the particles on the outer surface to stretch retaining a lot of elastic energy in that region [1]. This results in an overload of energy beyond the materials capacity and then cracks begin to form on the outer surface, in order to find the strain ( $e$ ) on the outer surface the following Eq. 3 is used, where  $R$  is the radius of curvature, and  $t$  is the thickness [1].

$$e = \frac{1}{\frac{2R}{t} + 1} \tag{3}$$

An expression for the minimum radius as presented in Eq. 4 can be achieved during bending and specific materials allow for a radius of zero, which indicates that the material can be folded on itself [1].

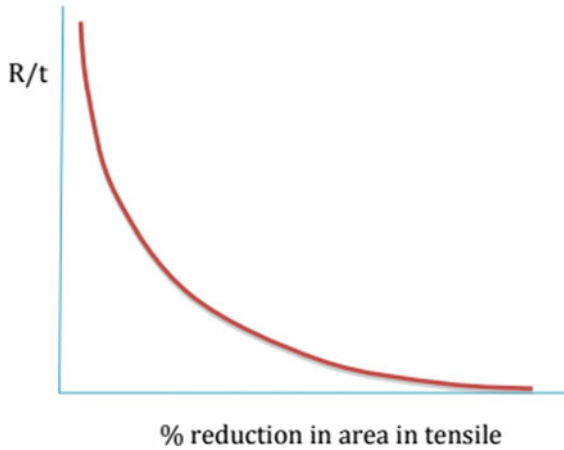
The minimum radius that can be achieved is expressed in the ratio of radius over thickness ( $R/t$ ):

$$\frac{R_{min}}{t} = \frac{1}{2r} - 1 \tag{4}$$

This expression is used to find the minimum radius allowable where  $r$  is the reduction area of the bended sheet. A 50% reduction in the bending area results in the minimum radius being zero; hence, the radius is equal to zero [1]. From the graphical expression in Fig. 3, we could see that the reduction area at the bent sight is inversely proportional to the minimum radius.

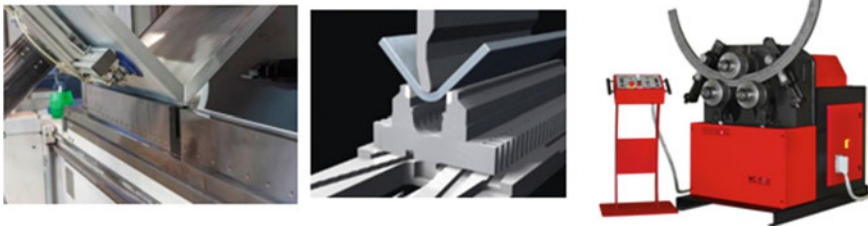
### 1.5 The Modern Method for Bending Workpieces in Manufacturing.

The bending process has expanded into many sectors in the engineering industries, and it continues to grow with new techniques and methods being developed for better economic growth in value due to quality but also not sacrificing the engineering integrity of the workpieces being bent. Many bending processes exist in industry but only a few will be addressed in this paper. The bending processes can be classified



**Fig. 3**  $R/t$  versus percentage reduction in area

into two categories, linear die bending and rotatory die bending. Linear die bending is conventional and simple, a gradual force is exerted on the punch and the punch gradually bends the workpiece at a constant velocity to form a desired product based on the applications [12]. Rotatory die bending involves a rotatory motion, a die specifically constructed for the bending process. The workpiece is placed in lower die, and the upper dies contain the rocker which makes contact with the workpiece and bends it in desired manner to obtain the desired shapes. Modern bending operation has been developed from ancient art practised by the armour makers and the immortalized village blacksmith. Nowadays, sophisticated equipment has been deployed into bending operation industries to replace punch and die techniques which are updated versions of the ancient methods of bending. Some of the new technologies used in bending operations are presented in Fig. 4 [2].



**Fig. 4** Today's bending Industry

## 2 Illustrative Case Study

The most common material that usually undergoes bending operation is metal. Different types of bend formation use different apparatus in the process of bending the specimen. The basic apparatus that is used in bend operations include the following: (a) punch, (b) die (c) pressure pad, (d) forming roll and (d) downholder.

### 2.1 Procedures

As these processes differ, so does the procedures that follow. The basic procedures to achieve sheet metal bending operations are itemized below. According to [5], these go through process analysis, simulative procedure, measurement, control and testing.

**Process analysis:** This is the first step into the process of bending. In order to understand extensively continuous bending as well as punch bending techniques, it is important to make an analysis of the tool design, the behaviour of the machines and the process design. In the process of punch bending, the first thing to be investigated is the behaviour of the cam disc machine that is used in the production series. To enable the use of the required measurement devices, the use of multi-body simulation models makes a possibility to obtain velocity and force general information.

The aim of the analysis is to get unambiguous machine behaviour, which includes the speed, the forces and the travel of an axis in the machine. The analysis also looks into the dimensional correctness of the parts produced by bending. It then goes into analysing the heating of the machine in the operation process, the specific machine characteristics and the effect of punch motion change.

**Simulative Technique:** The information acquired from the process analysis is utilized for demonstrating and simulating the bending process. A number of modelling strategies for metal bending process are developed [13]. For this situation, the simulation will serve to recognize both the important procedure parameters and the suitable commitment positions for correction activity. At that point, in view of these simulation models, the fundamental correction procedures are structured and investigated. This makes it conceivable to essentially decrease costly and tedious tests on the test facilities.

**Measurement:** Subsequent to process analysis, the following stage in the V-model is used to build up the measurement devices. To catch ordinary attributes of the part created, for example, a geometrical reference measurement, it is important to choose fitting sensors. To actualize the corrective action for changing a geometrical reference measurement, extraordinary actuators should be created. Sensors will quantify the current condition of the process and give the data to the control unit. The control unit gives the actuators the data required to change the ideal procedure variable. For this situation, the information of different parameters like elasticity or extension is not

significant to enlighten, the fact that it is wanted to address the deviation from the set point freely from these parameters.

The estimation technology in the punch bending process is utilized both for checking the bending process and for online procedure control. It is separated into two gatherings: one is for securing of procedure factors, for instance, the punch position and the bending force, while the other is for gathering of the significant parameters of semi-finished items. The difficulties for the estimation are exactness, elements and combination into the existing instrument. Laser sensors are hence chosen for position estimation, and piezo sensors for force measurement. For recognizing geometric dimensions, optical measuring devices can be utilized. A check should, be that as it may, be led to see whether the current market items are reasonable for gathering the prerequisites.

**Control strategy:** Self-correcting strategies are designed and used when using V-models. In the punch bending process, the test for the revision system lies in characterizing the factors from the shaping procedure which are of importance for online procedure control. The punch movements are utilized as impelling factors. The control system itself comprises of a feedback controller and disturbance compensator. The plan of the controller parameters is performed based on models utilizing streamlining algorithms. The controlled variable is an important geometrical normal for the work-piece for the opening measurement. On account of deviations of the real geometry from the wanted geometry, the corresponding axes will be modified.

In the event that the actual geometry of the genuine part is bigger than the ideal size, one probability is adjusting the punch movement to change the opening dimension of the following part. Various input variables must be handled, and numerous output variables must be discharged then record profile attributes of the opening measurement at various positions in the assembling procedure should be recorded to be utilized. A proper choice is the model-based plan of a multivariable control. Therefore, the control technique is first planned and tried on the model and after that executed on the genuine model plant.

**Testing:** The developments are analysed on test facilities as shown in Fig. 5a before being executed in the prototype system. Test facilities have been structured and built for the two processes. This makes it conceivable to investigate the conduct of the forming process under sensible conditions, while profiting by a laboratory circumstance. Therefore, as to re-enact the process forces, a hydraulic force-controlled cylinder is balanced in connection to the bearing block [14]. The object of the investigation included accomplishing right measurements on the mechanical and electrical segments. Further examination factors were the effect of backlash in the segments on the situating precision of the bearing block and its position retention exactness. The test facilities for the two procedures make it feasible to work independently of the machines utilized for arrangement generation which have high use rates. Along these lines, the estimation devices can be tried and enhanced, while having the control technique that has been created and executed in a modern control system. Figure 5b shows the details of bending [15].



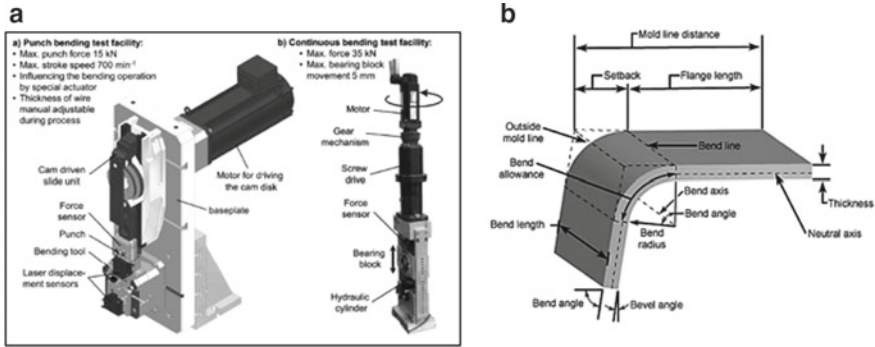


Fig. 5 a Test facilities [5], b nomenclatures in bending

Some of the products produced from bending types such as v punch and edge bending have been explored with the specific interest on L-shaped products. The product of each process is illustrated with the use of images and given a description based on the resulted image.

**V Punch Bending Operation Products**

Figure 6a represents the illustration of V bending process of an aluminium metal sheet that is subjected to a plastic deformation punch to form a 90° L-shaped product in Fig. 6b. The line of action or contact with the specimen is illustrated in Fig. 6a, and in Fig. 6b the punch has applied a punching force all the way in the specimen and stopped before it alters the thickness of the aluminium specimen.

**Edge Bending Operation Products**

Figure 4 shows how the press has deformed the shape of the aluminium specimen to produce the desired shaped product. From the V punch, it can be deduced that the angle between the planes after unloading the punch is on the specimen which is smaller than the bending die angle by a tolerance of around  $-1^\circ$ . This difference represents the spring-back phenomenon [16]. It can also be noted that the thickness of the material does not influence the spring-back value significantly. Observing the

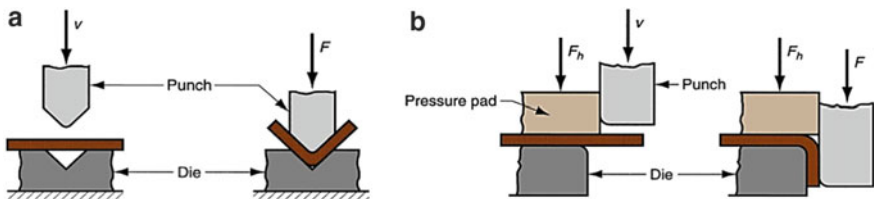


Fig. 6 a V bending, b edge bending

L-shaped specimen from edge bending Fig. 6b, the specimen forms the perfect shape as desired from the bending process. The differences learnt between the two, aside their nature of operations, have been that V bending is relatively easy to set up and the possibility for error is relatively smaller than edge bending.

### 3 Conclusion

Metal bending is a huge industry, especially for mass productions such as in automotive engineering where the body panels are punched out of sheet metal [17]. From the research and the discussions, it can be concluded that the basic types of bending include V bending as well as edge bending. It was established that when punch and die with the included angle are employed in the bending operation, it is called V bending whereas when the punch forces a cantilevered sheet metal section over a die in order to achieve desired and optimum bend angle, it is called edge bending. Other processes to be acknowledged for bending operations include air bending, beading, seaming, flanging and tube bending [18, 19]. From the bending operation explored on this assignment, it can be concluded that V bending can be used for larger sophisticated projects and edge bending can be used for relatively small projects. Irrespective of which method used, there is always a spring-back force on the material.

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