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DESIGN OF ROLL FORMING TOOL

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Abstract:

Sheet metal forming is widely used by the industries in the current scenario. Bending, Spinning, Deep drawing, Stretch forming & Roll forming are the major sheet metal forming processes. In this, roll forming is a unique continuous forming process, where 2D sheet metal is formed into various profiles like Roof tops, Window frames, Storage columns etc. by using series of mated rollers. This paper focuses on design considerations of roll forming tool and process parameters for a roll forming line. This design consideration discusses certain issues in design of roll forming toll which includes Unfold length calculation, Flower pattern design and roller design by using an analytical solution. The roller design includes the proper shaft selection, key & key way selection. This design is done based on force calculation. Major forces were considered to find the torque and bending moment. The results were demonstrated with specific profile illustrated prototype model and sample tool material (EN8). Small scale industries who have opted to manufacture their own roll forming machine can take this paper as suggested design consideration for forming tool.

Key Words: Roll Forming, Forming Tool Design, Flower Design, Force Analysis & Tool Material

Introduction:

Sheet metal forming processes are those in which force is applied to a sheet metal to modify its geometry rather than remove any material. Bending, spinning, deep drawing, stretch forming and roll forming are some of the sheet metal forming processes. Roll forming as shown in fig.1 is the continuous sheet metal forming process. In which the sheet metal is formed using series of mated rollers. This bend progression is dynamic where each stage of forming is continuously changes.

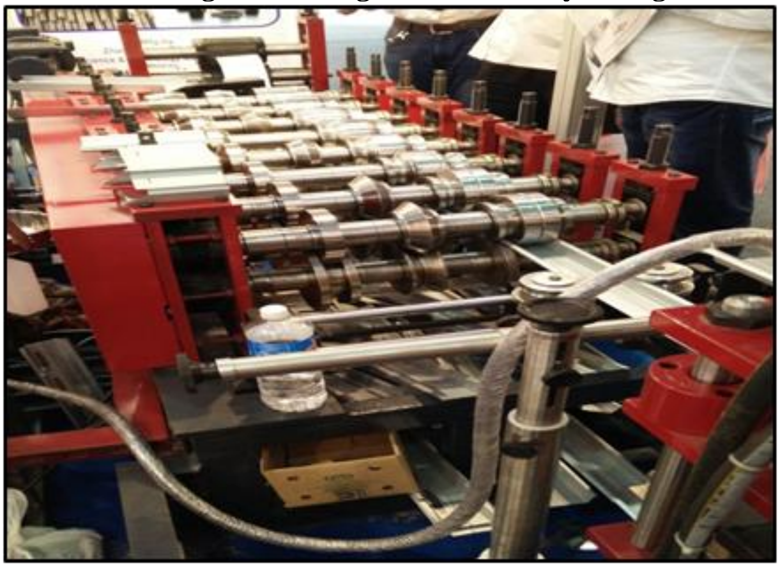


Figure 1: Roll forming process

In the field of manufacturing, roll forming plays a vital role which produces the product at high production rate at the same time the tooling process should be concerned. This roll forming process has many applications in both industries and domestic. For example, formed sheet material is used in window frames, guide rails in roads, table drawer, storage columns etc. Various cross section profiles (C, U Profiles) including intricate profiles also can be produced by using roll forming as shown in figure 2.

When a new roll forming machine is designed the tool designer must decide how many forming steps are required to form the profile. Various design parameters decides the forming tool design. In this paper, certain issues faced in a design consideration of roll forming tool is discussed.

To design a new roll forming line [2] following steps should be done.

- Development of cross sectional drawing
- Un fold length calculation
- Flower pattern design
- Design of rollers

In this paper this steps were analytically calculated to design a forming tool.

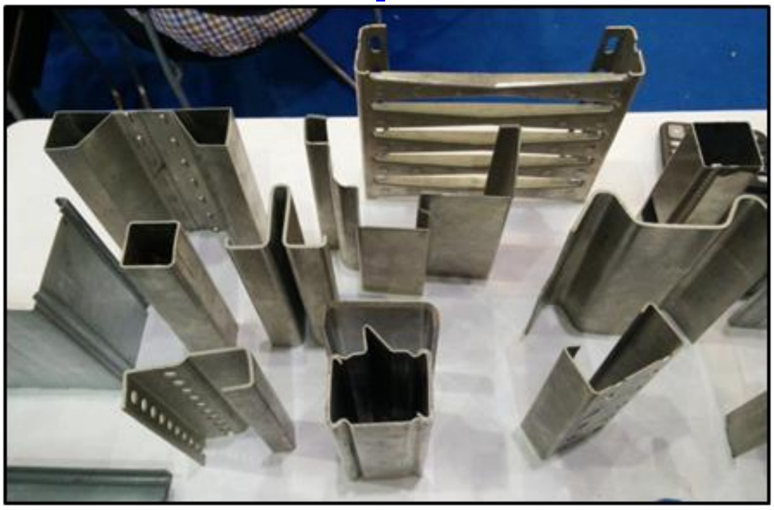


Figure 2: Various forming profiles

Methodology:

A sample 90˚ 'C' Profile is taken for design considerations for roll forming tool. The certain issues considered in the design of roll forming tool. The calculations are applied in the selected profile to obtain the final design for forming tool.

Design Considerations:

C – Type profile is taken for design consideration as shown in figure 4

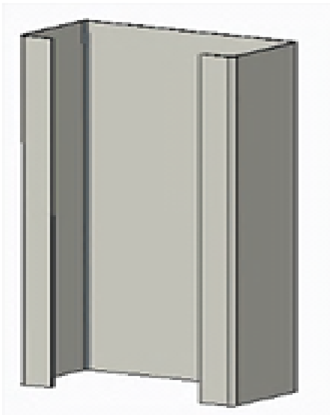


Figure 4: C – Type profile

('C' Shape profile with bend angle (θ) = 90˚; Web length (L1) = 150mm; Flange length (L2) = 65mm; Flange length (L3) = 20mm; Material Thickness (T) = 2mm)

Unfold Length Calculation:

Unfold length or strip width is an initial condition of sheet metal before fed in to the forming rollers. After determining the cross sectional view of the final profile, unfold length is calculated based on bend allowance and bend deduction calculation [11] [12]. Ordinary sheet metal bending calculations are modified to the roll forming application to find out the unfold length calculation. When calculating a strip width, using the proper K factor, or bend allowance, should be main concern. Various factors contribute to the bend allowance, such as material type and yield strength, profile characteristics such as large radii and roll design techniques

Bend Deduction:

The Bend Deduction as shown in figure 4 is defined as the material to remove from the total length of the flanges in order to arrive at the flat pattern. The flange lengths are always measured to the apex of the bend.

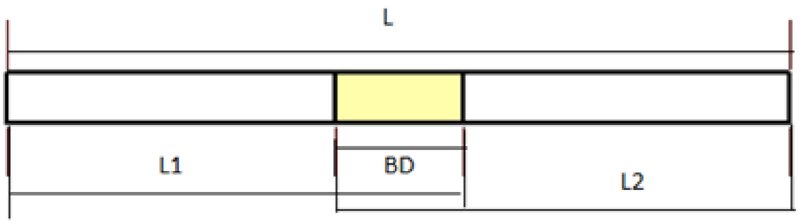


Figure 5: Bend deduction

Unfold length (L) = L1 + L2 – BD

Bend Allowance:

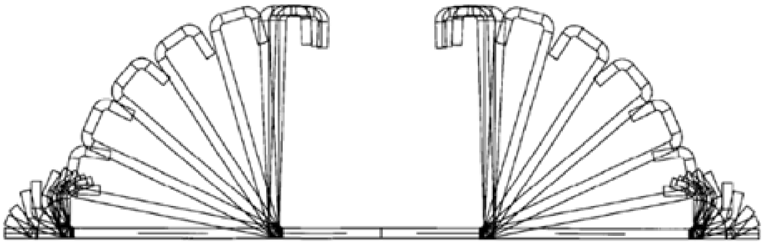
The bend allowance as shown in fig.5 is the arc length of the bend as measured along the neutral axis of the material.

Neutral Axis:

Looking at the cross section of the bend, the neutral axis is the theoretical location at which the material is neither compressed nor stretched.

K- Factor:

Defines the location of the neutral axis. It is measured as the distance from the inside of the material to the neutral axis divided by the material thickness; profile, bend allowance and bend deduction should be known. This can be calculated by using following formulae.



$$BA = \frac{\pi}{180}(A) * (R + kT)$$

$$BD = 2(R + T)\tan\left(\frac{A}{2}\right)$$

Unfold length (L) = D1 + D2 + BA

To find the total unfold length for the given

$$-BA$$

Where,
BA – Bend allowance; BD – Bend deduction;
A – Bending angle; R – Inner radius;
T – Thickness of the material

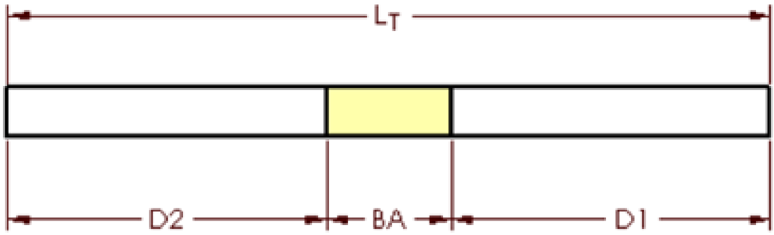
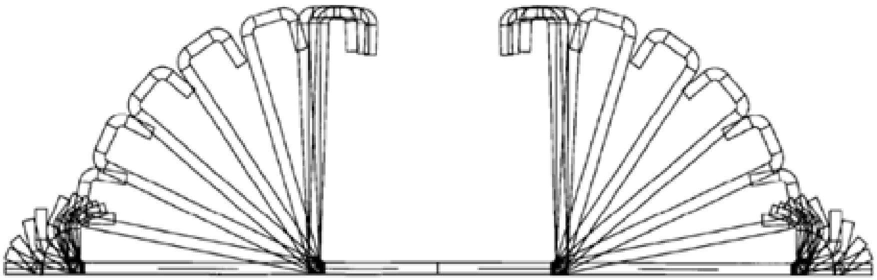


Figure 6: Bend allowance

For the selected profile, Number of bends is equal to 4. So, the final unfold length (L) will be equal to
(Web length + Flange lengths) – 4*BD

Flower Pattern Design:

After calculating the estimated strip width, Design progressed to develop the flower by using the arc and straight lengths. Basic design begins with an assessment of the required number of forming stages and individual configurations. In order to visualize the progress from the flat strip to final shape, intermediate shapes can be drawn superimposed, whereby one obtains flower diagrams such as shown in figure 7. Detailed consideration must be given to the inward flow of material between the forming stages. Too sudden a transition from one shaped stage to the next can cause longitudinal strain of the material. This can introduce residual stresses and give rise to bow or twist to the final product. The selection of the number of driven roll stages depends on the configuration of the shape to be rolled, qualified to some degree by the characteristics of the material.



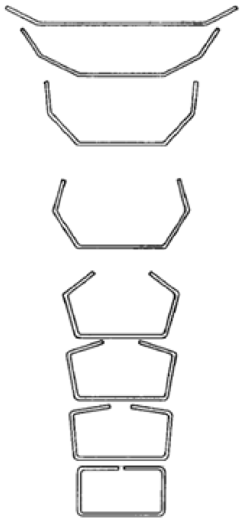


Figure 7: Flower Pattern design

This flower pattern is designed based on, yield strength of the material (i.e., AL – 55Mpa), Material thickness, Flange length [14]. These factors decide the forming angle in each stage. The following table 1 shows angle of progression in each stage.

Stages	Primary Profile	Secondary Profile
1	Flat rollers (0˚)*	Flat rollers (0˚)
2	0˚	18˚
3	18˚	18˚
4	36˚	36˚
5	54˚	54˚
6	72˚	72˚
7	90˚	90˚
8	Flat rollers (90˚)*	Flat rollers (90˚)

Table 1: Flower pattern progression

Constant bend angle increment of 18˚ is applied for the selected profile. This constant bend angel will reduce a longitudinal strain in the forming [9] [14]. At the start and end of the forming, Flat rollers are used to reduce the residual stress in the sheet material. The following figure 8 shows flower design for selected 'C' profile.

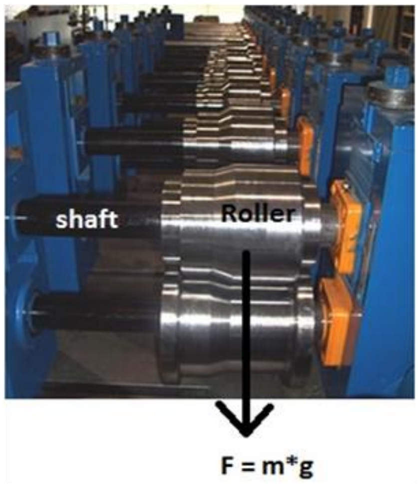


Figure 8: Flower design for selected profile

Design of Shaft, Key & Key Way:

In roll forming process, shaft is a mechanical element which transmits the power from motor to forming tool. This power is used to give the required torque to overcome the various forces. 4 major forces are considered in the design calculation of shaft.

- Self-weight of the roller
- Bending force required to bend the sheet metal
- Spring back force
- Rolling friction or Frictional force

Force Due to Self – Weight of the Roller:

To design a shaft and key, the design must be include the various forces induced in the shaft by external means. In this category of forces, First major force is *"Self-weight of the Roller"*. This force can be calculated by following method as shown in figure 9.

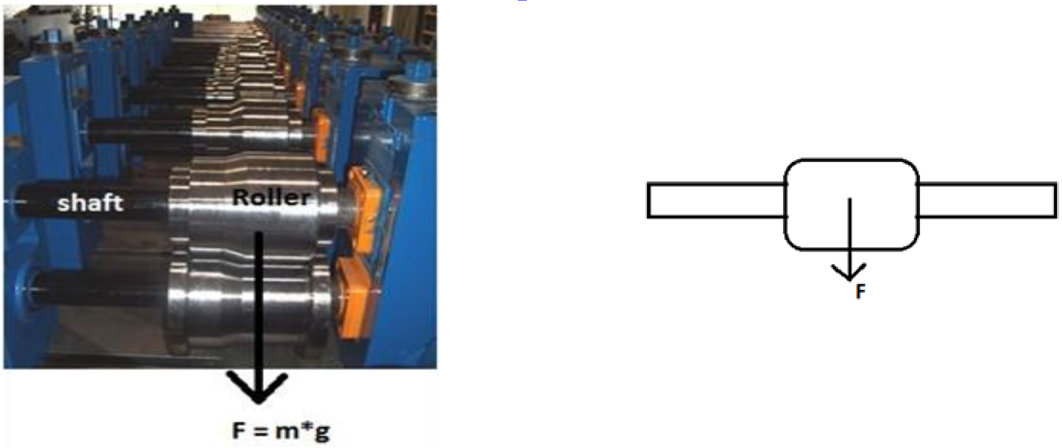


Figure 9: Self-weight of the roller

Self-weight of the roller acting on a shaft produce a force. This force can be measured by knowing the roller material density (EN8 = 7850 Kg/m^3).

Mass = Density * Volume

If the designed roller has a simple profile by using measurements formula, the volume is found. For a complex profile type, modeling software gives a volume for produced roller model.

Bending Force to Form the Sheet Metal:

Based on Literature survey [1] [7], bending force formula is found to calculate the force in roll forming. This force is a major in torque calculation. This force depends on the yield stress of material, the thickness of sheet, the bending angle of the pass, the total forming angle before the pass and the flange height.

$$F = \sigma\left(\theta p + \frac{3\theta c}{2}\right)\sqrt{\frac{2at^3\theta p}{3\,sin^2(\theta c + \theta p)}}$$

(Where, Yield stress of material (σ); Thickness of sheet (t); Bending angle of the pass (θp); Total forming angle before the pass (θc); Flange height (a))

Spring Back Force:

Due to elastic stress stored in the sheet metal, material tends obtain its original state. This reaction force in a sheet metal produces a spring back [7] [8]. This force depends on the yield strength of sheet metal. More yield strength produce more spring back force. This can be calculated by using bending force formula by changing the yield strength and angle of spring back.

Frictional Force or Rolling Friction:

Final major force that influences the overall torque in the shaft selection is frictional force. Friction between roller and sheet material produce a frictional force against a roller direction. Both top and bottom rollers affect the friction force. This friction comes under steel to steel rolling friction (μ = 0.05). This can be calculated by using normal friction formula,

(Where, μ – Co-efficient of friction; N – Normal force)

Selection of shaft:

$$T = I\alpha$$
$$\alpha = \frac{\omega}{t}$$
$$I = MK^2$$
$$Teq = \sqrt{Mb^2 + 2Mt^2}$$
$$d = \sqrt[3]{32\ Teq\ kt/\pi(\tau)}$$

After calculating the major force in the forming tool, torque required to rotate the shaft is found by using analytical calculation. Preferred shaft is found from the PSG design data book from page 7.22 to 7.25. The following flowchart fig.10 shows the steps in selection of shaft.

Where,

T – Torque (N-m)
I – Mass moment of Inertia (Kg – m^2)
K – Radius of gyration (m)
α – Angular acceleration (rad/sec^2)
ω- Angular velocity (rad/sec)
t- Time required (sec)
T_{eq} – Equivalent torque (n/m)
Mb – Bending moment (N-m)
Mt – Turning moment (N-m)
d- Shaft diameter (m)
K_t – Stress factor
τ- Shearing stress(N/m^2)

These are the various parameters that decide the shaft selection. After the selection of shaft proper key and key way is selected.

Key & Key Way Selection:

Key is a machine element used to connect a rotating machine element to a shaft. In roll forming it connects the shaft with roller. During the forming operation more torque is required to rotate the roller. This high torque induces a shear force between shaft and key. So the key must be with stand high torque. Standard key size available for the shaft and rollers.

Width and height of the key & key way is selected based on the shaft diameter. By using PSG data book pg. 5.16

Parallel Key and Keyway is selected (withstand more shear stress and high torque produced)

Selected shaft diameter	=	85 mm
Key cross section Width	=	25 mm
Height	=	14mm
Key way depth in shaft	=	9 ± 0.2 mm
In roller	=	5.4 ± 0.2 mm
Chamfer of key	=	(0.6-0.8) mm
Keyway	=	0.60 mm
Length of the Key (L)	=	63 -250 mm (Based on b x h)

Designation:

A Parallel key of width 25 mm, Height 14 mm, and length 150 mm shall be designated as,

"Parallel key 25 x 14 x 150 IS: 2048 – 1962"

Roller Design:

Roller is designed by using the dimensions obtained from the flower pattern design. Diameter of the roller is designed by using height of the cross sectional profile. To find the minimum diameter (D_{min}) 3 parameters should be considered. I.e. Shaft diameter (d), Key size (k), and material thickness (t) [13].

$$D_{min} = d + 2(k + m)$$

m – Minimum Roll wall thickness (Selected based on material thickness) as shown in fig.11. Maximum Roller diameter is obtained by adding the Final profile section depth (h) to it.

$$D_{max} = d + 2(k + m) + h$$

Material Wall Thickness (m)	
Material thickness (t)	M
Up to 1.9 mm	7.5 – 10 mm
1.91 – 3 mm	12 – 15 mm
3.1 – 12.7 mm	20 – 40 mm

Table 2: Material wall thickness (m)

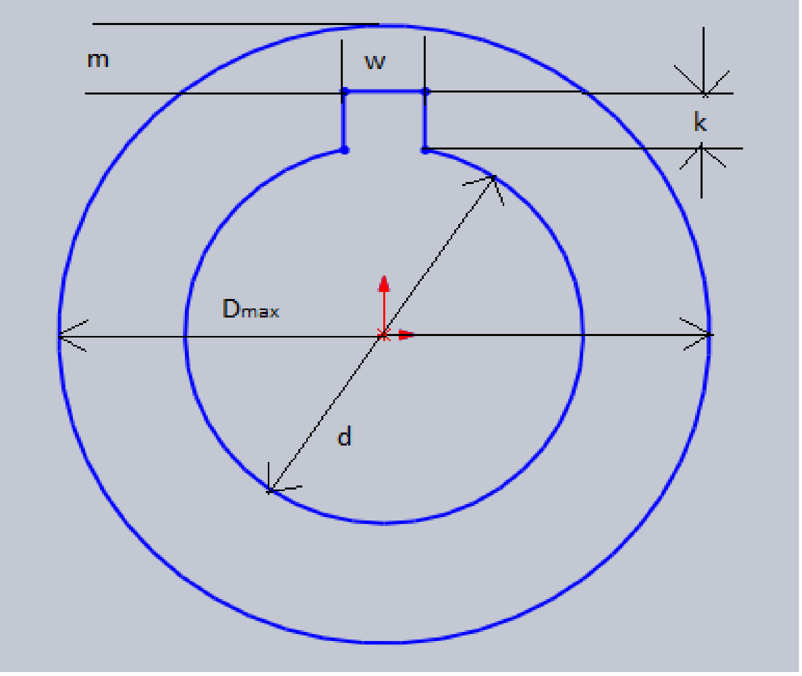


Figure 11: Dimensions of roller

Based on the above method, roller diameter is obtained for the selected C profile. These dimensions are calculated without considering the tolerance value. Based on the requirement by the user tolerance value will be assigned to the dimensions of roller. Positioning of top and bottom set of roller should be taken care. That decides the flow of sheet metal without affecting rollers.

Detailed Drawing for Roller Assembly:

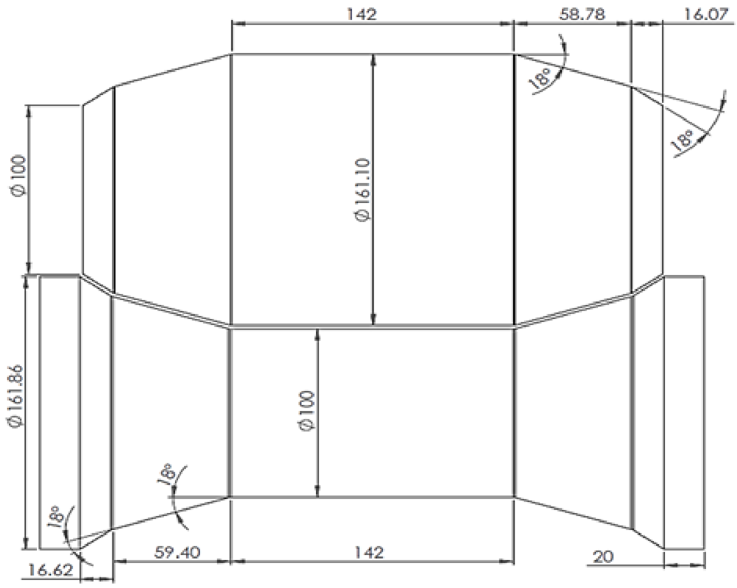


Figure 12: Detailed drawing (Reference: Stage 2)

The above figure 12 shows the detailed view of the roller model (Stage 2). Dimensions are based on flower design and calculation. Roll gap (gap between top and bottom roller) is theoretically equal to the sheet metal thickness. In practical, during the forming operation the thickness of the roller must be maintained throughout the process. So, the gap should be more than thickness. Also this will not produce more friction between roller and sheet metal [3].

Selection of Tool Material:

Carbon steels are widely used tool material in the field of manufacturing. Carbon steels are classified to 3 types. i.e. low, medium and high carbon steels. High carbon steel has good machining ability at the same time the cost of the tool material also high. To incorporate the cost factor in the design, medium carbon steel (C45 aka EN8) is selected as tool material. To improve the strength and machining ability, the material is subjected to heat treatment process.

Heat Treatment Process Parameters
Process: Hardening
Material: En8 (C45) Dim: (L 100 X Φ20) Mm
Temperature: 850˚C
Heat Treat Time: 30min
Cooling Medium: Quenching Oil with Chemical Bath
Cooling Time: 45 Min (30˚C)
Type of Furnace: Pit Furnace

Prototype Model:

To analyze the geometrical profile of the roller, prototype model is produced. Three major parameters are analyzed in the prototype model. i.e. Deformation length [1] which decides the distance between stands, Roll gap and Diameter of the roller [3] [4]. This prototype model is made with 3 stages (30˚, 60˚ and 90˚). Based on the literature survey deformation length is calculated by,

$$Deformation\ length = \sqrt{\frac{8a3\Delta\theta}{3t}}$$

Where, a – Flange length; Δθ – Difference in bend angle; t – Thickness;

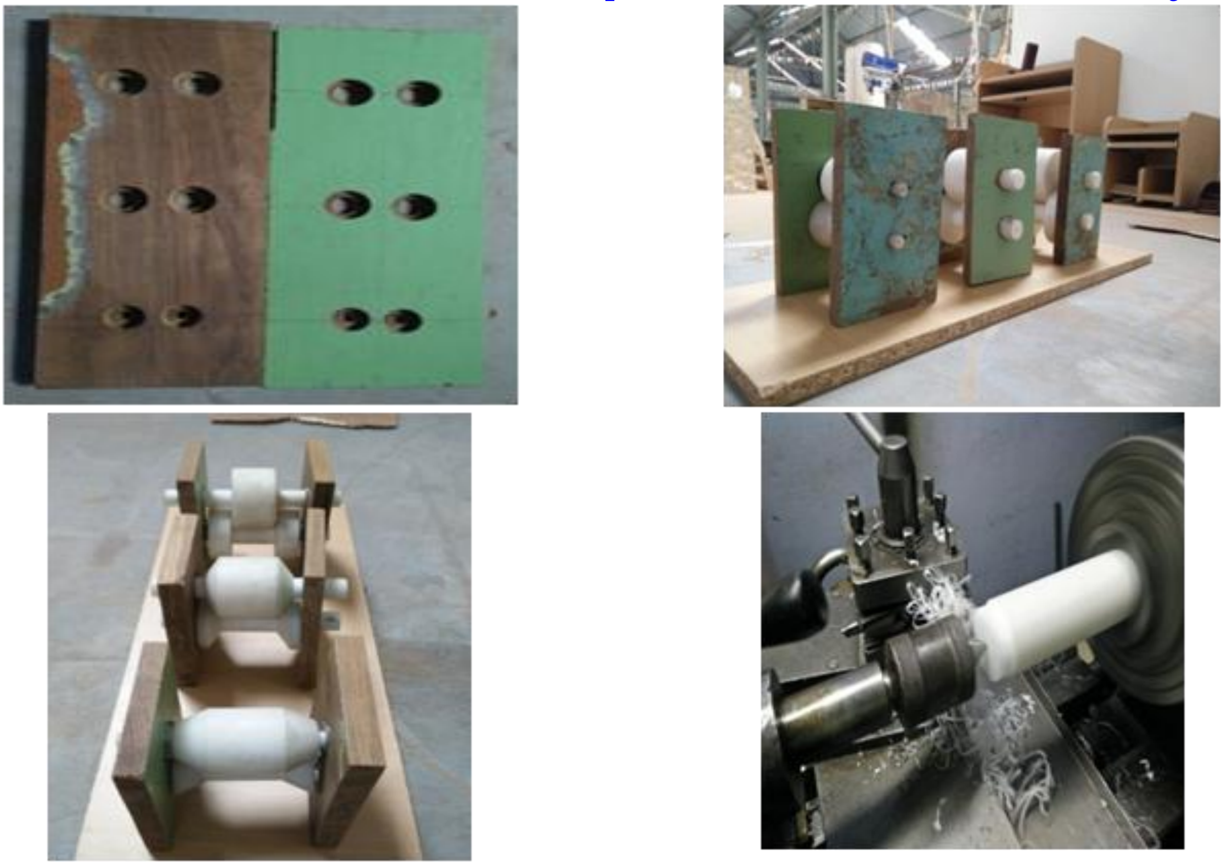


Figure 13: Prototype model

Based on the calculated deformation length, the prototype model is analyzed. Length below or above the calculated value gives wrinkling effect in the material which fed through the rollers. Also the gap between the rollers analyzed. More roll gap produce less friction between roller and material. This makes the roller to produce miss match between speeds. Roller diameter is calculated as shown in roller design chapter.

Conclusions:

Thus the various design considerations in roll forming tool is deliberated. Based on the above calculation, for the selected 'C' type profile:

Unfold length = 306.8 mm

Flower model is designed for the selected profile.

Force (with respect to 18˚ Roller set)

Self-weight of the roller = 150 N
Bending force = 43.415 KN
Spring back force = 7.68 KN
Frictional force = 58.5 N
Shaft diameter = 85 mm (First stage of rollers)
Material for forming tool = EN 8
Hardness - through heat treatment = 50HRC
Prototype deformation length = 146.3 mm

The above values are calculated for the selected profile from the illustrated method. This design can be further optimized by integrating artificial neural network (ANN) techniques to predict the flower pattern angle.

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