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*Full Length Research Paper*

# Study on roll forming of aluminum alloy tubes

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**Aluminum alloys are widely used in engineering structures and components, where light-weight and corrosion resistance are required. The roll forming process is successfully used for materials that are difficult to form by other conventional methods because of spring back, as this process achieves plastic deformation without spring back. In addition, the roll forming improves the mechanical properties of the material, especially, its hardness, and also increases the corrosion rate. In this study, an experimental investigation on roll compression forming of an aluminum alloy AA6101 tube is presented. Aluminum alloy tubes with an outer diameter of 40 mm and wall thickness of 2 mm, with a nominal tensile strength of 214 MPa, were compressed using a roll forming machine that developed pressures up to 150 kg/cm$^2$. It was found that a maximum of 15.5% reduction in the outer diameter without failure was achieved during roll forming at a pressure of 42 kg/cm$^2$. The post forming hardness, corrosion rate, micro structure and deformed grain size were also studied.**

**Key words:** Roll forming, aluminum alloy, hardness, micro structure, corrosion rate.

## INTRODUCTION

The roll forming process is one of the most common techniques used in the forming process, to obtain a product as per the desired shape. In this process, sheet metal, tubes and strips are fed between successive pairs of rolls that progressively bend and form, until the desired shape and cross section are obtained. The roll forming process adds strength and rigidity to lightweight materials such as aluminum, brass, copper and zinc, composites, some heavier ferrous metals, specialized alloys and other exotic metals (Anne, 2007). Aluminum alloys are used in many engineering industries, especially in automotive and aerospace applications, because of their excellent corrosion, wear resistance and good formability on the surface (Karthikeyan et al., 2010). The objective of the numerical finite element (FE) and experimental investigations was to determine the optimal process for the production of a tubular product, with simple tools and standard forming processing machines, without defects and with the expected dimensional accuracy. The optimal dimensions of the tubular product with the required process stability were obtained. The results of the numerical FE simulations of the process were verified by experiments (Mandic et al., 2006). The experimental and computational investigation of the roll forming process is feasible to develop the profiles successfully on complex geometries in high strength steels (Michael, 2009; Pervez, 2010). An exhaustive literature review reveals that the proposed methodology was not reported for this type of roll compression forming process, using an aluminium alloy AA6101 tube. In this work, a study of the effect of pressure levels on roll compression forming is presented. The aluminum alloy AA6101 tubes were formed using standard roll compression forming equipment. The changes in the tube outer diameter, post-forming hardness, corrosion rate and microstructure were measured, by using standard equipments.

### EXPERIMENTAL PROCEDURE

The outer and inner roller in conjunction with a hydraulic cylinder was used to compress the aluminum alloy AA 6101 tubes. The schematic diagram illustrating the experimental set-up is shown in

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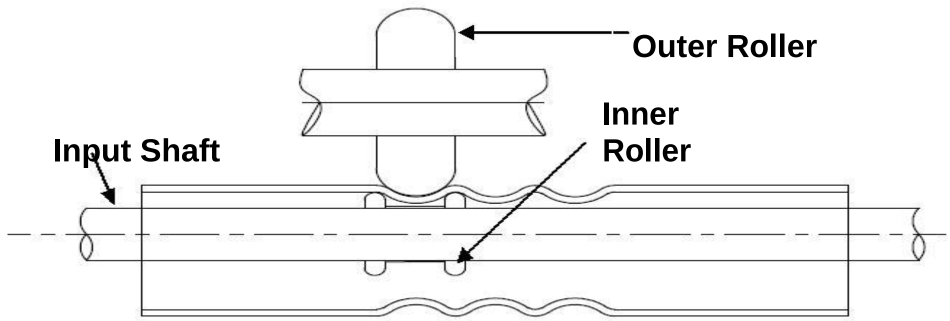



**Figure 1.** Schematic representation of the roll forming process

**Figure 2.** Front view of the typical experimental configuration.

**Table 1.** Properties of the aluminum alloy AA6101.

| **Tensile strength, ultimate** | **214.4 MPa** |
|---|---|
| Tensile strength, yield | 188.11 MPa |
| Modulus of elasticity | 70 MPa |
| Poisons ratio | 0.33 |
| Fatigue strength | 205 MPa |
| Shear strength | 257 MPa |
| Thermal conductivity | 121 W/m-k |
| Melting point | 570-650 C̊ |
| Density | 2700 $Kg/m^3$ |
| Electrical conductivity | 2.655 Mho/m |

Figure 1. The experiments were conducted at different pressure levels to evaluate the deformation rate, hardness, micro structure and grain size using advanced instrumentation.

#### Experimental set-up

The experimental setup consists of a roller, hydraulic cylinder and an input shaft, which allows the aligning of the tube and permit the tube to be located over the input shaft, as shown in Figure 2.

The machine has a maximum cylinder capacity of 150 $kg/cm^2$. The pair of rollers acts as a die to form the required shape on the tube. Rollers are made of mild steel to withstand the high load. There are two rollers, namely, the inner and the outer rollers. The outer roller is used for applying the necessary pressure over the work piece to obtain the convolution over the tube. This roller is mounted over the input shaft. The inner roller is used to form the internal shape of the processed tube. It is the preset value of the inner size of the aluminum alloy AA6101 tube. The main purpose of the input shaft is to provide mechanical power, which is connected to the motor through a gear chain mechanism. It transmits the mechanical power and the two successive inner rollers which are mounted over the shaft. The hydraulic cylinder is used to actuate the movement of the outer roller, and is controlled by a ram movement. The capacity of the hydraulic cylinder varies for different pressure levels ranging from 0 to 150 $kg/cm^2$. The job is placed over the right position where the forming process takes place. During the process the outer roller can be moved in the y-direction up to the required dimensions of the component. The pressure is applied as an input to obtain the required component.

#### Materials

All the specimens were cut into lengths of 150 mm and an outer diameter of 40 mm with a thickness of 2 mm. The tensile strength of the work material is 215 MPa. The chemical composition of the aluminum alloy AA6101 was found to be 0.387% Mg, 0.384% Si, 0.208% Fe, and 98.96% Al. The properties of the aluminum alloy are summarised in Table 1.

## RESULTS AND DISCUSSION

### Effect of the pressure levels on tube compression

The work pieces were positioned outside the input shaft in the overlap configuration. The pressure levels less

**Figure 3.** Roll forming compression test at different levels of pressure.

than 14 kg/cm$^2$ were not considered, as it did not have an appreciable effect on formability. The maximum pressure was limited to 42 kg/cm$^2$, as further increase in the pressure level caused failure. Hence, the experiments were conducted at different pressure levels of 14, 21, 28, 35 and 42 kg/cm$^2$. The roll forming of the compressed aluminum alloy tube specimens for various pressure levels from 14 to 42 kg/cm$^2$ are shown in Figure 3.

A minimum of three tests were conducted at each pressure level to check the reproducibility. The final outer diameter of the non–round deformed tubes was estimated by taking the average of the outer diameter. The reduction in the outside diameter at various pressure levels is tabulated in Table 2. The results show that the maximum percentage reduction in the outer diameter by roll compression after the experiment is 15.5%. As the pressure level increases, there is a gradual decrease in the outer diameter of the AA6101 tube.

## Variations of the hardness with the pressure level

The Vickers Micro Hardness test was conducted at five different specific control points, along the thickness of the parent and post forming aluminum alloy tubes at various pressure levels. The aim of this test was to capture the variation in the hardness that may appear after the roll forming process is completed. The AA6101 tube is tested for Vickers hardness and microstructure analyses. In the hardness test, the formable area is cut along the longitudinal and transverse sections, and samples are prepared for testing. The hardness results obtained at various pressure levels are tabulated in Table 3. As the pressure level increased, the hardness also increased slightly relative to the base materials, which in turn, increased the property of the materials. The hardness has gradually increased from 73.0 HV to a maximum of 78.8 HV at the maximum pressure level of 42 kg/cm$^2$.

## Microstructure analysis

The microstructures of the parent material and the tubes made by roll forming are displayed in Figure 4 (a-b). The parent material did not show the grain flow along the direction of its formation in the transverse direction, whereas the entire roll formed tubes showed a banding of grains along the direction of forming. The micro structure shows the AA6101 wrought aluminum alloy matrix that indicates the precipitated particles of $Mg_2Si$ in the aluminum solid solution. The grain size of the specimen before forming is higher as compared to the grain size of the specimen after the roll forming process. The grain size of the parent material is 45 microns while 25 micron grains size is obtained for the roll formed specimen at a pressure level of 42 kg/cm$^2$**.** This, in turn, caused a slight increase in the mechanical properties, specifically the hardness in the roll forming processed aluminum alloy AA6101 tubes. From the grain size in the roll forming processed tubes, it also can be understood that residual stress (which is a common phenomenon in cold working) might exist, as the grains are smaller, and there is direct contact between the tool and the tube. The forming process is completed fastly and also allows the material to get a spring back, and hence, reduces the grain size of the aluminum alloy AA6101 tubes.

## General corrosion test

The AA6101 tube under a pressure level of 42 kg/cm$^2$ is taken for the corrosion study, and is cut into two pieces, to test both the formed and unformed portions for the Salt Spray test as per ASTM B-117 standards. The corrosion study was carried out with a Sodium chloride concentration of 10 % and pH maintained constant of 7.0 for 72 h. The standard measurement of the corrosion rate is expressed as in equation 1 (http://www.corrosionist.com/corrosion_rate_conversion.htm). The corrosion rate of the unformed and roll formed specimens are shown in Table 4.

$$\text{Corrosion rate} = \frac{2.22504 \times W}{D \times A \times T} \quad (1)$$

where

W - Weight loss of specimen (mg), D - Density of the material of the specimen (gm/cm$^3$).A - Surface area of the specimen (centimetre$^2$), T - Time of exposure in hours.The corrosion rate of the unformed portion of the AA6101 alloy is 3.99 × 10$^{-8}$ mpy, which increases with the increase in time; and the corrosion rate of the roll formed portion of the AA6101 alloy is 4.60 × 10$^{-8}$ mpy at 42 kg/cm$^2$, which also

**Table 2.** Summary of the experimental results.

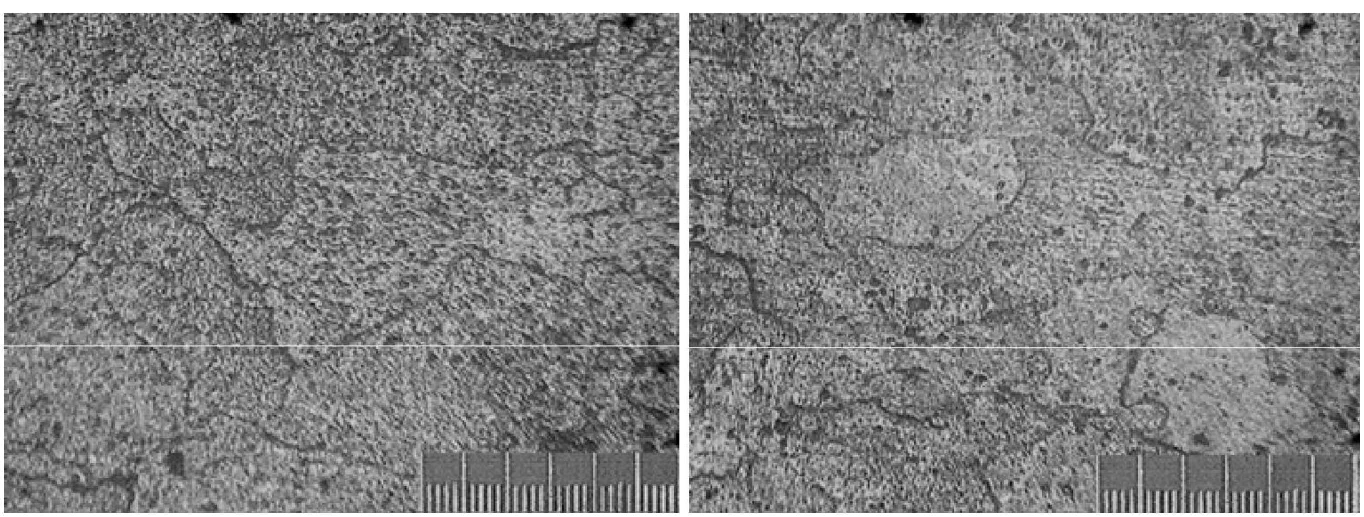
| Pressure level ($kg/cm^2$) | Final outer diameter by experiment (mm) | Reduction in outer diameter by experiment (%) |
|---|---|---|
| 14 | 39.24 | 1.9 |
| 21 | 38.56 | 3.6 |
| 28 | 37.80 | 5.5 |
| 35 | 36.30 | 9.25 |
| 42 | 33.80 | 15.5 |

**Table 3.** Vickers hardness at different pressure levels.

| S/No. | Pressure level ($kg/cm^2$) | Vickers hardness (HV) |
|---|---|---|
| 1. | 14 | 74.2 |
| 2. | 21 | 75.2 |
| 3. | 28 | 76.7 |
| 4. | 35 | 77.5 |
| 5. | 42 | 78.8 |

**Table 4.** Corrosion rate of the unformed and roll formed specimens.

| S/No. | Specifications | Test results of AA 6101 unformed portion | Test results of AA 6101 Roll formed portion |
|---|---|---|---|
| 1. | Initial weight ($w_1$) | 31.197 g | 34.202 g |
| 2. | Final weight ($w_2$) | 30.977 g | 33.945 g |
| 3. | Density (D) | 2.7 $g/cm^3$ | 2.7 $g/cm^3$ |
| 4. | Time of exposure (T) | 72 h | 72 h |
| 5. | Length of specimen | 5 cm | 5.5 cm |
| 6. | Outer radius of the specimen | 2 cm | 1.85 cm |
| Corrosion rate | | $3.99 \times 10^{-8}$ mpy | $4.60 \times 10^{-8}$ mpy |



**(a)** Parent alloy **(b)** Roll formed specimen at a pressure of 42 $kg/cm^2$

**Figure 4.** (a-b) Parent and roll forming processed aluminum alloy tubes.

increased with an increase in the time. The stress retained by the work piece is partially higher due to the outer roller's contact with the work piece, which is evident from the corrosion studies. Considering the advantages on the mechanical properties and forming feasibilities, the corrosion properties are marginally higher.

## Conclusions

Studies on the roll forming of aluminum alloy tubes were conducted, and the following conclusions are drawn:

1. Roll compression forming of aluminum alloy tubes was conducted successfully. It was found that a maximum reduction of 15.5% in the outer diameter could be achieved during roll forming at a pressure of 42 kg/cm$^2$.
2. It was observed that as the pressure level increased, the hardness of the tube also increased.
3. The values of the Vickers hardness test show an increase of 5.6 HV at a pressure of 42 kg/cm$^2$.

The grain size reduced at the peak pressure of 42 kg/cm$^2$, thereby increasing the mechanical properties of the alloy. The corrosion rate of the roll formed portion of the AA6101 alloy was higher compared to the unformed portion. Considering the advantages on the mechanical properties and forming feasibilities, the corrosion properties are marginally higher.

## REFERENCES

Anne MH (2007). A Textbook of Material Forming Processes. ISTE, First South Asian edition.

http://www.corrosionist.com/corrosion_rate_conversion.htm.

Karthikeyan L, Senthil Kumar VS, Padmanabhan KA (2010). Bi – Axial Stressing of Sheets of Friction Stir Processed Aluminum Alloy A319. Int. J. Mater. Manuf. Process. 25(11):1297–1303.

Mandic V, Stefanovic M, Zivkovic M (2006). FE analysis of tube forming process with experimental verification. J. Achiev. Mater. Manuf. Eng. 18(1-2):303-306.

Michael I (2009). Experimental Investigation and Analysis of the roll forming process. Ph.D Thesis from Lulea University of Technology.

Pervez T (2010). Experimental and numerical investigation of expandable tubular structural integrity for well application. J. Achiev. Mater. Manuf. Eng. 1(2):147-154.