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Experimental Study on Strength Deformation Behavior of Large Diameter Thin-Walled Aluminium Alloy Tubes Subjected to CNC Bending

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Abstract

The strength deformation behavior of thin walled aluminium alloy 6063 tubes under flexure has been presented. The effects of deformation, thinning, thickening of the tube wall surfaces, ovalness of the tube and springback angleat critical cross sections of the aluminium tubes are studiedunder different computer numerical control (CNC) bending conditions. Aluminium alloy tubes of 25mm outer diameter, 390 mm length and varying thickness of 1, 1.5 and 3mm have been used for testing. It is observed that, thinning and thickening of inner and outer bend of tube gradually rises with increase in the bend angle and meantime surface flattening and non-circularity of tube in terms diameters also upsurges for the increase in bend angle.Furthermore, experimental outcome of deformed tube is compared and characteristic result for effect of experimental parameters is found to be in good agreement with literature values.

1. Introduction

The recent pasts have appealed immense applications of curved tubular parts in automobile, aerospace, oil industries where high strength/weight ratio elements are needed [1, 2]. The defectsoccurring in the tube due to bending process are of prime concern and should not be neglected. There are a number of parameters that can be controlled in a manner such that,their focus is committed towards one particular aim of reducingsuch defects. For example, geometry parameters of tubes, wall thickness, outer diameter-to-wall thickness ratio D/t, centerline bending radius-to-outer diameter ratio R/D and friction conditions are some of these parameters which can be usually modified to maintain the instability [3].In the tube forming process, the wrinkling and variation in the wall thickness and cross section distortion are the common defects [4]. Thus, any deviation of such process parameters, leads to possibility of over-thinning, section distortion or even wrinkling, and these phenomena occur more easily for thin-walled aluminum alloy tubes with small bending radii [5].The wrinkling often happens in the inner part of the bending tube, while the cross section distortion happens in the outer part, which should be avoided.The key to realize stable and precise bending forming is to select sound process parameters in order to control the stress and strain states, and thus the thickening, thinning degrees of ovalization and springback angle of the bending tubes can be controlled to some acceptable extent under free wrinkling.Thus the NC bending process can be used to formulate laws for large diameter thin-walled aluminum alloy tubes, particularly effects of process parameters.Considerable amount of research has been carried out on bending of thin walled tubes by use of experimental and FEM techniques. Moreover stress and strain distribution, tube wall thinning, cross-section ovalization and other defects in the NC bending have been studied[6-9]. However, not many studies have been reported on NC bending process for large diameter thin-walled aluminum alloy tubes.

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Teng et al. [10] conducted experiments on thin-walled tubes under bending with internal pressure to clarify the deformation behavior. A study of response of the internal pressure on the thickness distribution, bending limit, section flattening of the thin-walled tube was studied. It was observed that, as the internal pressure increases, non-circularity of tube initially decreases tremendously and rate of decrease goes down, stability and bending limit of the tube improves, reduction in wrinkling, thinning ratio of extrados ascends and thickening ratio of the intrados descends. Mathon et al. [11] performed experiments to record the behavior for increase in internal pressure to differentiate global collapse and local buckling. It was found that buckling is restricted on a limited areas of the shell and also the behavior of post-buckling is stable, which leads to buckling stress is lesser than collapse load. Miller et al. [12] extruded aluminum tubes using bend stretch forming process-I. Here bend-stretch-forming facility is used to study the distortion in cross sections in extruded Aluminium tubes. It was concluded that distortion in cross-section and can be reduced by using modest level of pressure under stretch form bending. Limam et al. [13] conducted experiment and analysis on inelastic wrinkling and collapse in tubes under combined bending and internal pressure. They observed small amplitude axial wrinkle on compressed side of tube, as bending progress their amplitude also grows ultimately outward bulge will form due to localization of wrinkle, causes a catastrophic failure in the form of outward bulge. Increase in both the wavelength of wrinkle and curvature at collapse is due to internal pressure. The FE shell model was used for the progression of the wrinkling and its subsequent localization is successfully simulated. Also they found a very small difference between experimental value and initial imperfections required for the calculated failure curvature. Yang et al. [14] summarized advances of forming technologies in tube bending. The multiple failings, springback, bending features, thinning of wall, distortion in wall and forming parameters are conversed. The advanced trends and corresponding tasks were presented for comprehending the accurate and high competence tube bending distortions. Heng et al. [15] tested size effect in aluminium alloy tube having thin-wall under nonlinear bending. Rotary draw bending is accompanied to authenticate theoretical prototypes and further endorse size effect associated bending formability for the tube of numerous diameter and thickness. They have shown that cross section distortion, wrinkling, wall thinning will increases for tube possessing big diameter and small thickness. The relationship between stress-strain has also been established.Heng et al. [16] accompanied springback behavior in cold bending process of thin-walled aluminium alloy tubes. They explored both FE model and experimental method for nonlinear geometry dependent angular springback and radius growth by deliberately changing the tube thickness and diameter. They have showed that as diameter increases tangent tensile strain raises and proportional coefficient decreases. As a result springback get reduced. Whereas when thickness upsurges tangent tensile strain reduces but proportional coefficients get amplified so that angular springback and its radius get augmented. Sozen et al. [17] predicted springback using CNC tube bending operation. Major influencing parameters on springback like coefficient of friction between die and tube, axial loads and internal pressure in tube were discussed. It was found that with the increase of bending angle springback also increases. This springback is controlled by using axial pull, raising frictional coefficient between tube and die and internal pressure for different bending angles. The springback angle was checked by creating number of mandrel balls like one, two, three etc. It was finally concluded that number of mandrel balls does not adversely affect the variation of springback angle. Sedighi et al. [18] examined the influence of filling material in bending defects of thin-walled tube. A sequence of experiments are conceded by filling the tube with different rubbers and liquefied loads to learn wrinkling, cross sectional warp and dissimilarity in wall thickness. It was concluded that rubber material reduces bending defects for a

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particular range whereas the low temperature metal filling material completely avoids it. Movement of neutral axis towards inner layer is restricted by filling material. As a result the compression decreases and tension rises in inner and outer fiber. Thus, based on the literature cited above, the present work is one such attempt to conduct experimentation on thin walled aluminium tubes in order to study the factors influencing deformation behavior likewall thinning and thickening at outer and inner fibers of the tube, springback angle of tube and ovality of tube at critical cross section.

2. Materials and Methods

Based on material strength, properties, machinability and durability, aluminium alloys are widely accepted for variety of applications. Amongst these,aluminium alloys of the series 6XXX are the ones'used for commercial purposes. Irrigation tubing, architectural applications, window frames, extrusions and doors, shop fittings, balustrading the rails and posts are usually the area of applications of aluminiumalloy-6063. Most of the above mentioned applicationsinvolve various machining operations of the alloy such as bending, pressing and rolling. Amidst these operations, the bending operation involves reasonable level of complexity as bending of thin-walled aluminium tubes involves greater chances of defectiveness. Thereforethin-walled aluminium alloy 6063 tubessubjected to bending were studied in order to understand theirstrengthdeformation behavior.The basic mechanical properties (Table 1) of the tubes were obtained using uniaxial tensile test, in which the specimens were intercepted along the tube axes.

Initially based on the availability of tube bending die, trial bending experiments for a bending angle of 90^0 were conducted on sample test specimens of prescribed outer diameter and thickness. These tests were conducted in order to confirm the failure of the test specimen under bending.The literature as well as experimentation of test specimen clearly states that most bending defects are observed in thin-walled tubes. Therefore, according to the availability of bending dies and tubes, the tubes of constant outer diameter 25mm with varying thicknessof 1, 1.5 and 3mm were employed for experimentation.The experimental parameters were as follows: varying load of 2kN per minute; bending angle of 60^0, 90^0 and 120^0, varying tube thickness of 1, 1.5 and 3mm respectively; the mandrel extension length ranged from 10 mm to 20 mm; and the mandrel had 2 or 3 balls.It is imperative to note that, most tube bending operations are carried out in the presence of the internal pressure. The presence of the internal pressure under tube bending tends toreduce the defects such as wrinkling, ovality, and thinning occurring to the tube material. Therefore thin-walled aluminium alloy tubes with freely filled sand as internal pressure provider have been used for bending operation. Here,sand is freely filled into the tube and corked to both ends to avoid overflowing. Tube bending operation is undertaken under both presence and absence of the internal pressure (sand) and the deformation behavior is tabulated.

3. Experimentation

The deformation behavior occurring during bending operations were carried out in a Universal Testing Machine (UTM). However the UTM does not consist of requisitesthat can be used for handling a tube bending operation. Thus a bending die is prepared according to the required bending radius and fastened to the UTM in order to carry out the bending operations. Three wooden dies shown in Fig. 1 are prepared according to a particular bending radius for 3 different bending angles 60^0, 90^0 and 120^0. Since the UTM possesses a ram at the top and bench at the bottom, it is imperative to have a female and male die for tube bending and is shown in Fig. 2.Wooden dies are prepared according to the radius of curvature of initial bent tube and then projected to 60^0, 90^0 and 120^0 bending angle. The radius of

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curvature is calculated graphically from a reference tube which is initially bent in CNC tube bending machine. These grooves made in the wooden dies are based on theouter diameter of the tube and give support to the tube while tube bending by compression.

The material Aluminium alloy 6063 tube is further tested for ovalization, wall thickening and thinning by using CNC tube bending machine. Here, the material used for bending is of length 390mm which is due to constraint of the machine. The computer controlled program is updated in the form of computer aided design for conducting the bending operation. Dies of bending radius of 50mm and 100mm are used for the experimentation. Test specimen is clamped to the bend die using clamping die which is actuated by hydraulic pressure. The tube is bent to a required bending angle with help ofpressure die. The pressure die is working using hydraulic actuator and which will draw and bend the tube according to the program.

Table 1- Mechanical properties of thin walled Al-6063 tubes

E/GPa	$\rho/(g/cm^3)$	υ	σ_{yt}/MPa	σ_{ut}/MPa	BHN
69.5	2.7	0.33	241	215	75

E is elastic modulus;ρ is density; υ is Poisson ratio; σ_{yt} is Ultimate yield stress; σ_{ut}isultimate tensile stress and BHN is Brinell hardness number.

Fig. 1: Bending dies of 60^0, 90^0 and 120^0

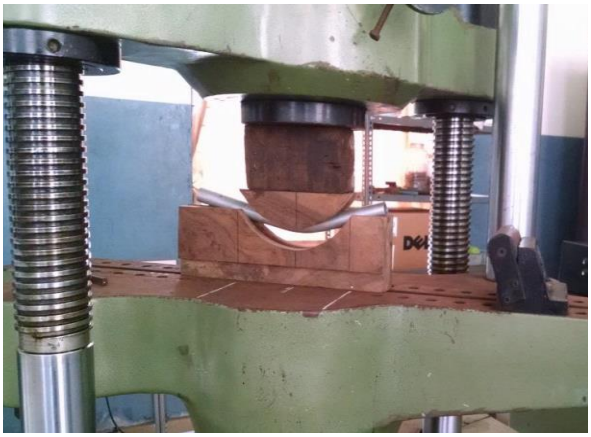

Fig. 2: Male and female die used in bending

In deformed tube the outer bend is called as extrados and inner bend is named as intrados. When a tube bent to particular angle generally due to deformation tubes get ovalization near the critical cross section. The whole deformed cross sectional diagram for tube bending is shown in Fig. 3. Here ODmax and ODmin abbreviate maximum outer diameter and minimum outer diameter which represents width and height of deformed tube respectively. The tubes will get oval shape at the critical cross section under tube bending. This change in shape is measured manually by using Vernier caliper. During tube bending outer bend of the tube undergo tension and inner bend experiences compression. Outer wall thickness experiences thinning due to tension mean while inner wall get thickened due to compression action. NDT method is used to measure the value of thinning and thickening at outer and inner tube bend. Generally, an ultrasonic thickness detector (refer Fig. 4) is used to measure thickness of the material in NDT method.

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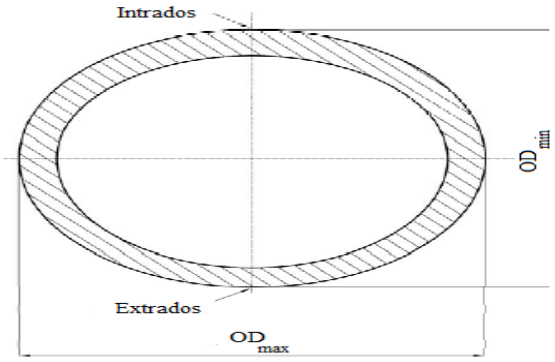
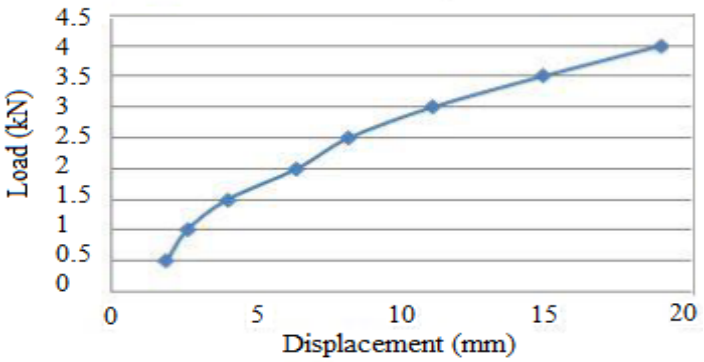


Fig. 3:Diagram for critical cross section of tube after deformation.

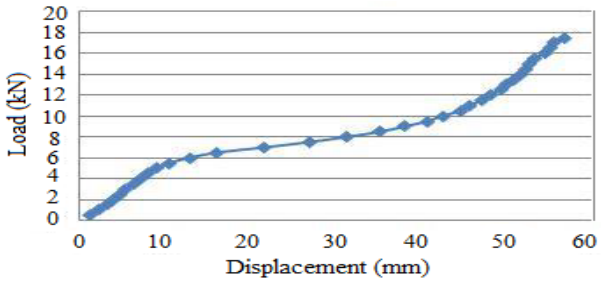
Fig. 4: Ultrasonic thickness detector.

4. Results and Discussions

Generally in UTM a point load is applied. Initially the two extreme ends of the die acts as support to the tube which has to be bend. When load is applied primarily male die comes into contact with tube at the center of the tube. All the three 1mm, 1.5mm and 3mm wall thick tubes with length 390mm specimens are undergone bending operation. The load is applied gradually around 2 KN per minute on the tube. For each increment in load, the displacement is recorded.



(a)



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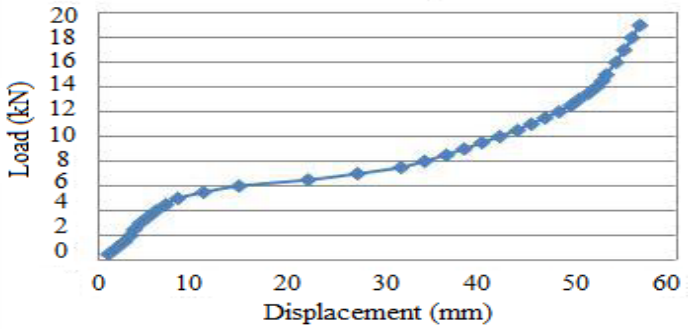

(c)

Fig. 5: Load v/s Displacement for Tube of thickness 1mm bent to a) 60^0, b) 90^0, C) 120^0.

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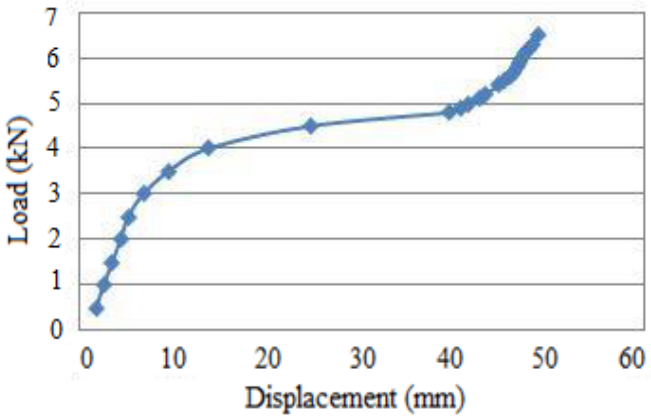
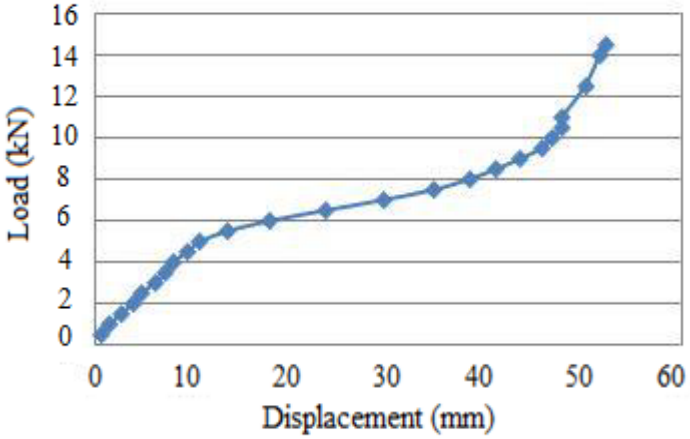
It is observed from Fig. 5 that, deformation of 1mm tube diameter increases withincrease inthe load. Here, the tube started to get flat near the supporting edges and gradually tubes are losing its shape near the support edges. When load is applied the extreme ends of the dies acts as a simple supports to tubes. So the applied load is not uniformly acting on the tube and is concentrating on the tube near the supporting end. For a 60^0 bend shown in Fig 5a, when the applied load reaches to 4KN, flattened part of the tube near the supporting ends is clearly observed. Further loading will cause the pipe to get flatten more and more near the supporting ends. So the load applied to the tube is not actual load to carry out the bend required. Furthermore, Fig. 5b and Fig. 5c is for tube of wall thickness 1mm is bent to 90^0 and 120^0 and it is observed that deformation of tube increases with rise in the load. The flattening of the tube is observed when load reaches to 4KN. But in this case further loading is proceeded to observe the failure of the tube shape. As a result it is observed that beyond 4KN, tubes get flattened very fast near the supporting end than achieving the bend. So the tube consumes more load than load required to it to bend to 90^0 or 120^0.





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