Materials Research Proceedings 44 (2024) 52-59 https://doi.org/10.21741/9781644903254-6

Research on circumferential tension-axial shear loading of thin-walled aluminum alloy tubes

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Keywords: Thin-Walled Tube, Tensile and Shear Stress State, Circumferential Tension-Axial Shear, Strain Path, Aluminum Alloy

Abstract. The deformation of parts with complex shapes is under a tensile and shear stress state. The deformation characteristics of materials under the tensile and shear stress state are beneficial for improving the prediction accuracy of the deformation of parts with complex shapes. A loading method of circumferential tension-axial shear of thin-walled tubes using two semi-circle mandrels and one specially designed tubular specimen is proposed in this paper. An experimental device was developed according to this method using servo electric cylinders. A thin-walled 5052 aluminum tube was tested and the strain path of the center point of the deformation zone was analyzed. This loading method can be used to investigate the characteristics of tubular material under the tensile and shear stress state.

Introduction

Parts with complex shapes deform under a tensile and shear stress state [1, 2]. Understanding the deformation characteristics of materials under a tensile and shear stress state is beneficial for improving the simulation accuracy of the deformation of parts with complex shapes [3]. Tension and shear loading tests of thin-walled sheets are achieved by applying shear force in one direction and tensile force in the orthogonal direction. Mohr conducted the tension and shear loading experiment of TRIP700 steel sheets. It is indicated that the prediction accuracy of the Mises criterion is poor for the condition when the ratio of tensile stress to shear stress is smaller than 0.5 [4]. Pijlman utilized the tension and shear loading results of AA5182 aluminum alloy sheets to establish an anisotropic constitutive relation based on the Vegter model. The strain distribution of parts with irregularly shaped sections during the deep-drawing process is accurately predicted [5]. Zheng investigated the influence of pre-deformation on the formability of 6K21-T4 aluminum alloy sheets. It is indicated that the ultimate strain of the sheet is reduced by the equi-biaxial tensile and shear pre-deformation when the ratio of tensile stress to shear stress is smaller than 1, while the ultimate strain is increased when the ratio is larger than 1 [6].

Due to the limitations of tube shape, research on the tensile and shear deformation of tubes has not been reported so far. Wang used a pair of semi-circle mandrels to exert force along the axial direction on a specially designed tubular specimen. The pure shear deformation along the axial direction is achieved at the interface plane between the two half tubes of the specimen [7]. Based on the principle of axial pure shear loading of tubes, the circumferential tension and axial shear test is proposed by applying a tensile force perpendicular to the interface plane. An experimental device was developed and a thin-walled 5052 aluminum tube was tested. The strain path of the tube during the tensile and shear deformation process was analyzed in this paper. This loading method can be used to investigate the characteristics of materials under a tensile and shear stress state.

Principle of circumferential tensile-axial shear deformation

Based on the axial pure shear principle of thin-walled tubes, the circumferential tensile-axial shear deformation is achieved, as shown in Fig. 1. The interface plane of the two half tubes of the specimen is the pre-set deformation zone. A tensile force F_θ which is perpendicular to the interface plane of the two half tubes is applied to the mandrel, which causes circumferential stress σ_θ in the deformation zone. Under the combined loading of axial force F_z and tensile force F_θ, the deformation zone is under a tensile and shear stress state.

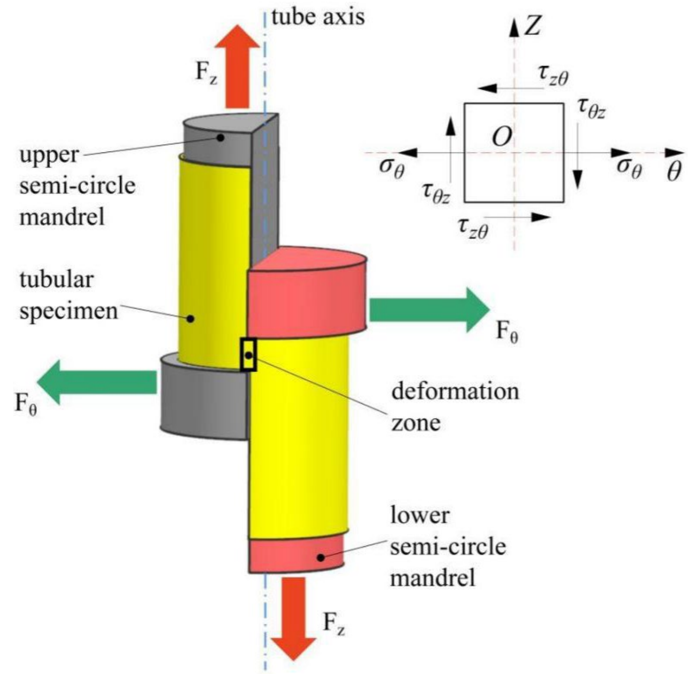


Fig. 1. Principle of tensile and shear deformation of tubes.

The interface plane is subjected to shear stress and tensile stress. The shear stress is calculated according to Eq. 1:

$$\tau_{\theta z} = \frac{F_z}{2*L*t} \tag{1}$$

and tensile stress according to Eq. 2:

$$\sigma_\theta = \frac{F_\theta}{2*L*t} \tag{2}$$

where L is the real-time axial length of the deformation zone, and t is the real-time wall thickness of the tube.

Development of the circumferential tension-axial shear experimental device

As shown in Fig. 2, the experimental device for circumferential tension-axial shear loading is composed of a frame, servo electric cylinders, and a Digital Image Correlation (DIC) measuring system. The specimen and the mandrels are placed along the horizontal direction. A servo electric cylinder placed along the horizontal direction is connected to the lower mandrel, applying a movement along the axial direction of the tube to the mandrel. Two servo electric cylinders are placed along the vertical direction. The two vertical servo electric cylinders are connected to the upper and the lower mandrels respectively, applying vertical tensile force to the mandrels. There are force sensors installed on each servo electric cylinder to measure the force. In the deformation zone, the shear stress is along the axial direction of the tube, while the tensile stress is along the circumferential direction. To ensure that the tensile force and axial force are orthogonal, a pair of linear guide rails are installed on the two vertical sides of the frame. The vertical servo electric cylinders are installed on the guide rails. The frame and the cylinders are shown in Fig. 3, wherein the maximum load of each servo electric cylinder is 37 kN.

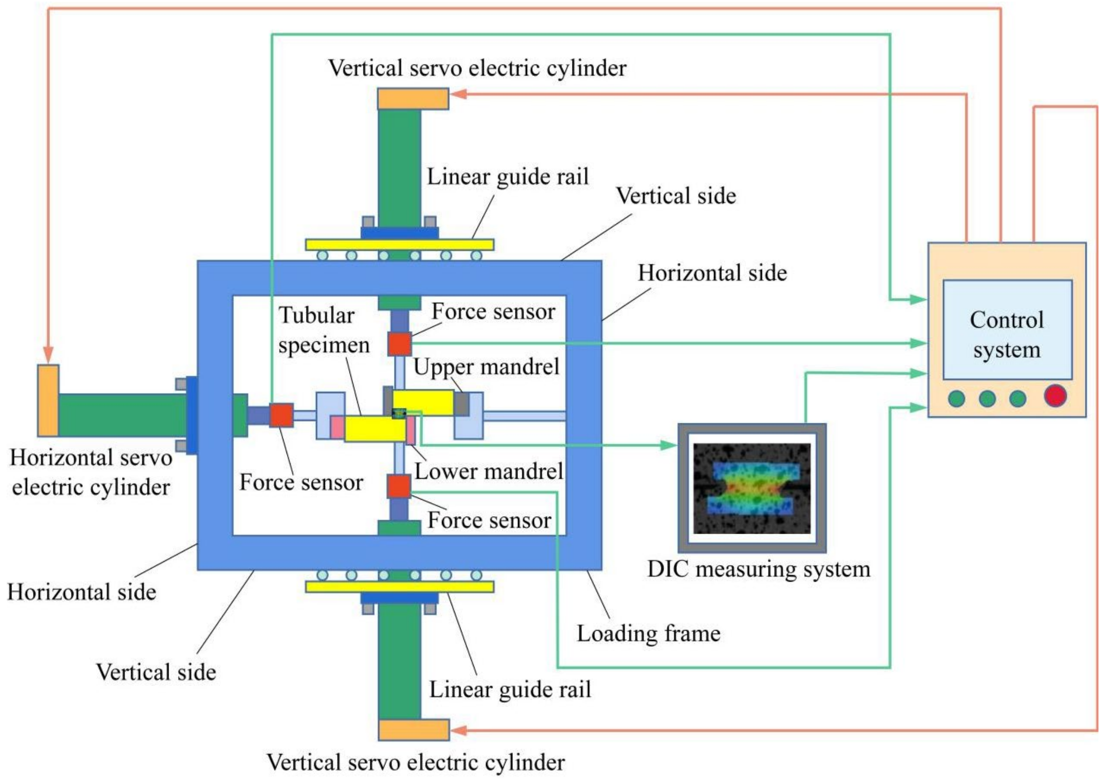


Fig. 2. Principal of circumferential tension-axial shear loading device.

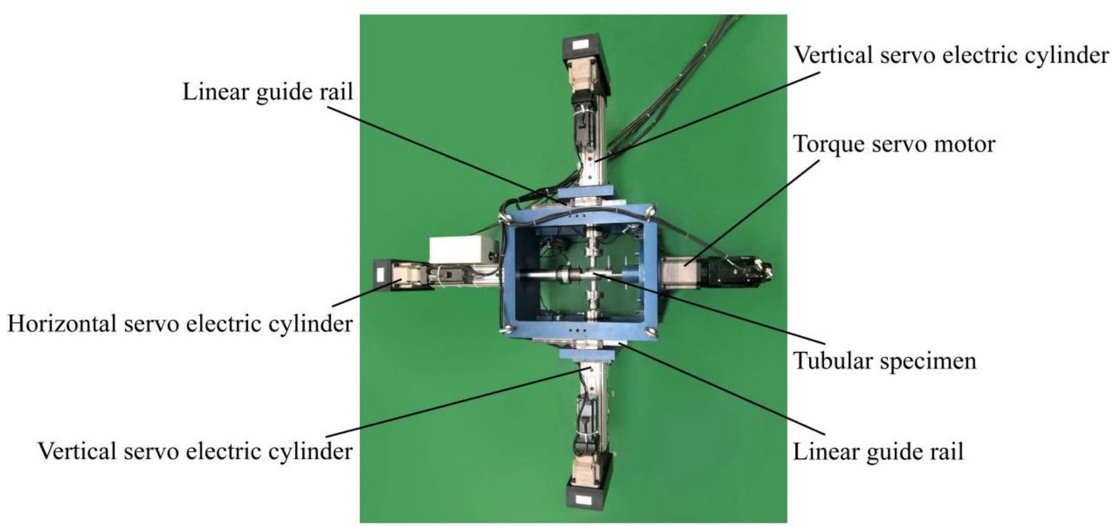
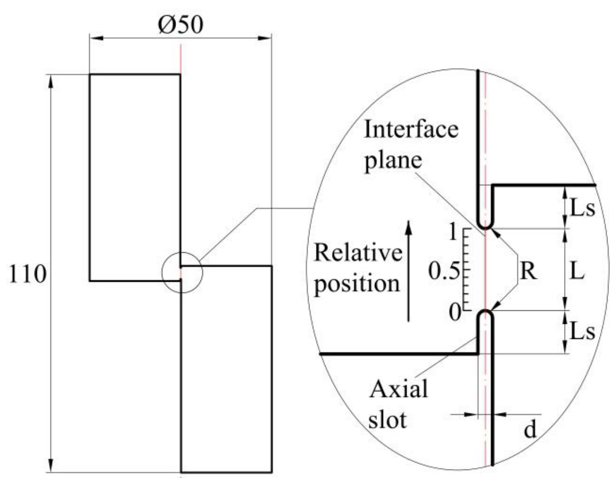


Fig. 3. Frame and cylinders of the experimental device.

Circumferential tension-axial shear loading experiments

A thin-walled 5052 aluminum alloy tube with a nominal dimension of 50×1.2mm was used in the experiment. The tubular specimen is shown in Fig. 4. The length of the deformation zone L is set to L/t = 10. Long grooves with the half-circle notch are machined at both ends of the deformation zone to minimize the influence of the force from the mandrel on the stress state. The axial length of the slots Ls is set to Ls/t = 2.5, the width d to d/t = 1, and the notch radius R to R/t = 0.5. The outer diameter D of the semi-circle mandrel is 47.5 mm, leaving a gap of 0.05 mm between the mandrel and the inner wall of the tube.

(a) Specimen



(b) Dimension(unit:mm)

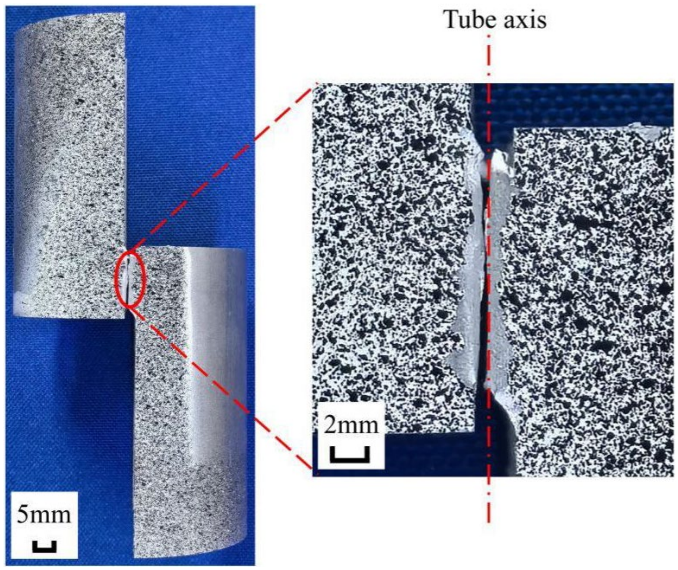
Fig. 4. Tubular specimen.

Experiments were carried out using the loading plans in Table 1. The cracked specimens are shown in Fig. 5. For Loading plan 1, the crack surface in the deformation zone is flat, while the crack surface is inclined relative to the tube axis for plan 2. For both plans, no significant necking is exhibited on the specimen before cracked.

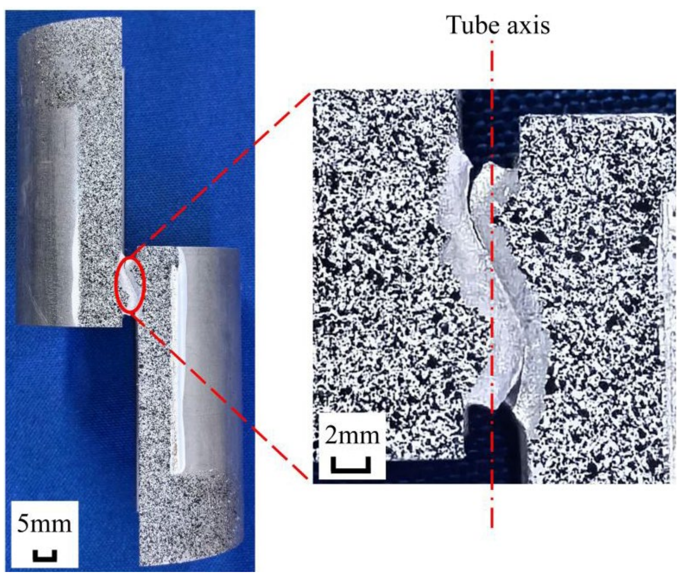
Materials Research Proceedings 44 (2024) 52-59 https://doi.org/10.21741/9781644903254-6

Table 1. Loading plan.

No.	Loading parameters
1	The ratio of tensile stress to shear stress is 0.5 until cracked
2	The ratio of tensile stress to shear stress is 2 until cracked



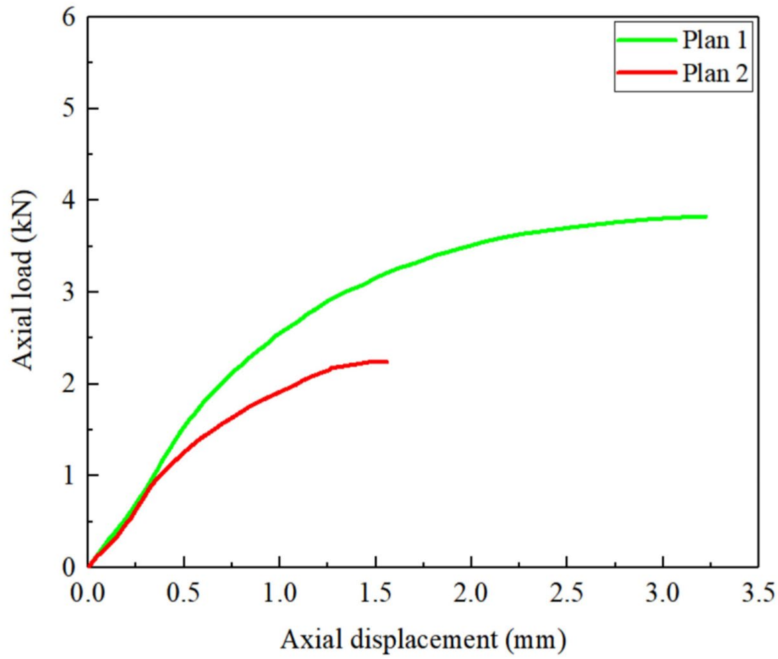
(a) Plan 1



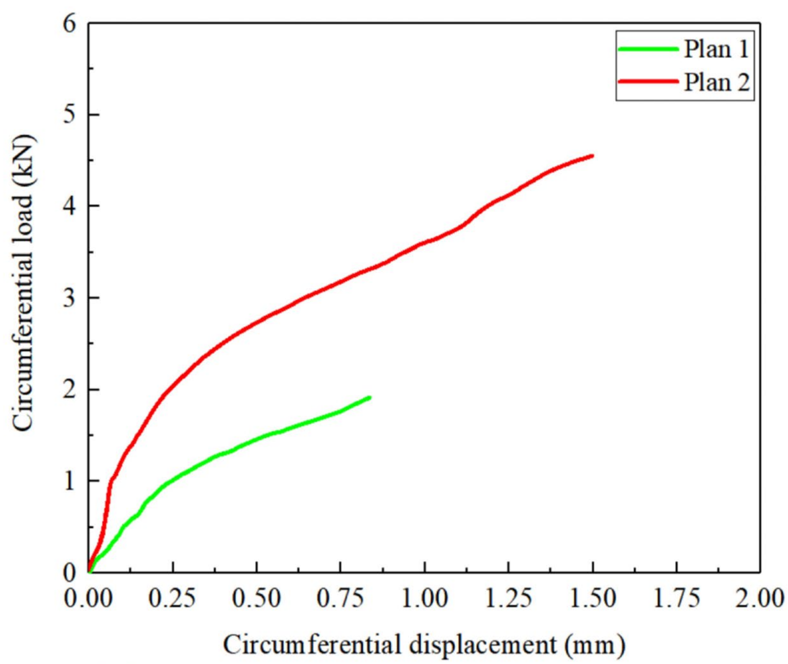
(b) Plan 2

Fig. 5. Cracked specimen.

The axial load-displacement curve and the circumferential load-displacement curve are shown in Fig. 6(a) and (b), respectively. The endpoint of each curve corresponds to its maximum value.



(a) Axial load-axial displacement



(b) Circumferential load-circumferential displacement

Fig. 6. Load-displacement curve.

The strain path of the center point of the deformation zone is shown in Fig. 7. The strain path of the tube under the circumferential plane strain tensile deformation is also shown. For plan 1, the strain path is in the range of pure shear to uniaxial tension, and the strain path for plan 2 is between plane strain tension and uniaxial tension. It is shown that the strain path between pure shear and plane strain can be achieved using this method by changing the ratio of shear stress to tensile stress.

The next work is to investigate the influence of the shear stress on the forming limit of the thin-walled tubes under tensile-shear stress state.

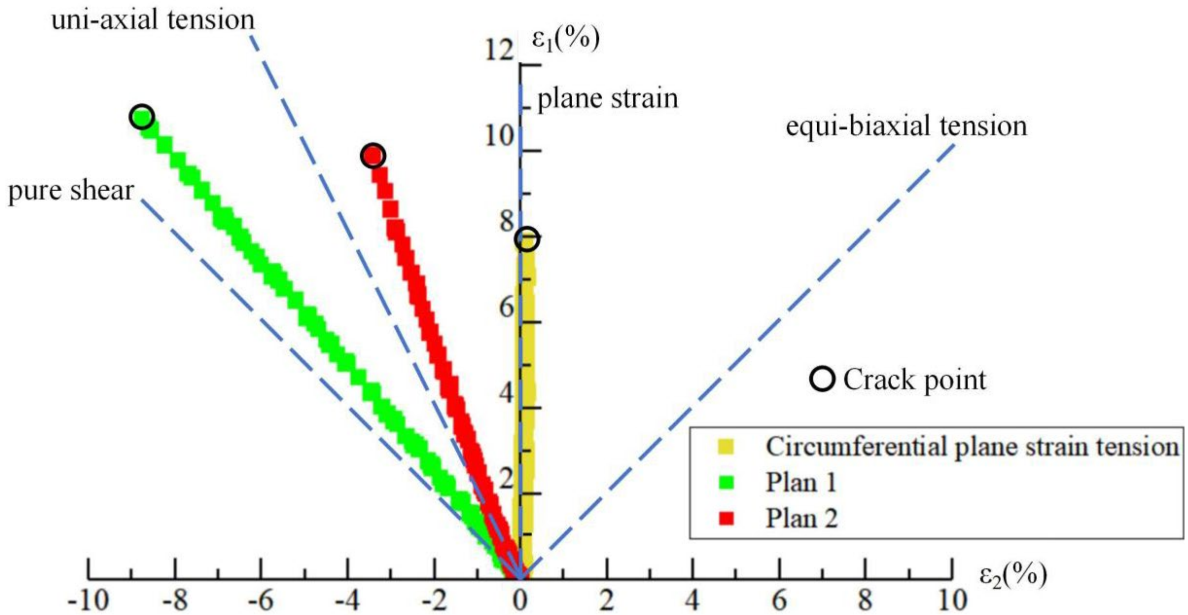


Fig. 7. Strain path.

Conclusions

A loading method for circumferential tension-axial shear of thin-walled tubes is proposed in this paper, an experimental device is developed and an aluminum tube is tested. The strain path of the tubular specimen between pure shear to plane strain tension can be achieved using this experimental device. The deformation characteristics and forming limit under a tension-shear stress state will be investigated in future work.

Acknowledgments

Financial assistance of the National Natural Science Foundation of China, Project 51975147, is acknowledged.

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