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Effect of internal pressure on microstructure of tube shear hydro-bending of 5A02 aluminum alloys

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Abstract: In order to study the effect of shear deformation on microstructure, the formed shear hydro-bent tube of aluminum alloy was investigated by using electron back scattered diffraction (EBSD). The effect of internal pressure on the microstructures of the outside and inside corner zones was analyzed. The results show that the grain size is 50−100 μm at outside and 30−50 μm at inside under the internal pressure of 15.2 MPa, while the grain size of the undeformed tube is 100 μm. When the internal pressure reaches to 38.0 MPa, the grain is further refined and the grain size becomes 30−50 μm at outside and 10−20 μm at inside. The shear deformation plays an important role in the microstructure of two corner zones. The grain in the corner zones is refined and the size is becoming smaller with the internal pressure increasing. The grain size of inside is smaller than that of outside even if the internal pressure is the same for the different deformation degree.

Key words: hydroforming; microstructure; EBSD; tube; aluminum alloys

1 Introduction

In recent years, hydroforming has been widely used for manufacturing automotive hollow components in European and North America [1−3] and tubes for aerospace and aircraft in China [4−5]. Shear hydro-bending is a new method and an expanded application of hydroforming to manufacture integrated elbow tubes with small bending radius. An elbow tube is often employed in narrow space. It is widely used in hydraulics and fuel piping on the advanced aero turbine engine for its high reliability, light mass and small occupied space [6].

At present, the elbow tubes with small bending radius are usually manufactured by welding two stamped halves. Therefore, the reliability of tubes is affected by the welding seams. Integral forming of the elbow tubes can not only improve reliability, but also save mass and space [7].

However, the elbow tube with small bending radius can not be manufactured by conventional bending processes including CNC bending, press bending and push bending. The essential deformation of these bending processes is tensile at outside and compressive at inside. Therefore, there is a limited value of relative bending radius, for example, the limited value R_b/d=1.0 for aluminum alloys 5A02. In case of R_b/d<1, there is winkling at inside and fracturing at outside [8−9].

GOODARZI et al [10] studied the shear bending with mandrel for Z-type tube. TANAKA et al [11] investigated the zero bending by using liquid pressure as supporting media.

Shear hydro-bending is a forming method to realize material flowing and bending process by shearing deformation. The mechanism of the bending method is changed from the tensile-compressive to the shear deformation. The liquid medium is employed to support the tube. The internal pressure plays an important role in the shear hydro-bending process. There is a reasonable window of the internal pressure, in which the tube can be successfully formed without defects. Otherwise, folding or crack defects will occur. The detail of the shear bending process was reported in Ref. [12]. In this process, the plastic deformation is severe and the grain size is affected, which is related to the performance of the formed part.

Electron back scattered diffraction (EBSD) is an SEM based tool that provides orientation information from crystalline materials [13−14]. This is achieved

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through the analysis of the reflection of electrons characteristic. As well as orientation information, there is also the potential for determining the degree of plastic deformation [15].

In this work, the microstructure of the shear hydro-bent tube was investigated by using electron back scattered diffraction method. The effect of the internal pressure on the microstructure of the corner was studied.

2 Experimental

2.1 Principle of shear hydro-bending

In shear hydro-bending process, the shear deformation of the tube is obtained by the movable die going along the fixed die in transverse direction. The axial punches are sealing and feeding at the same time. During the forming, the liquid medium is employed to support the tube, as shown in Fig. 1.

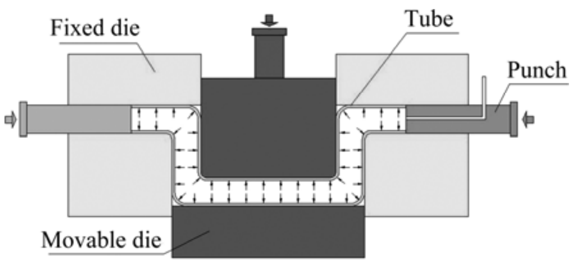

Fig. 1 Principle of shear hydro-bending

2.2 Tube material

The material used in the experiment was 5A02 aluminium alloy. The yield stress of the material is 76 MPa and the elongation ratio is 22.8%. The outside diameter and the thickness of the tube are 30 and 1.5 mm, respectively.

2.3 Machine and tooling

The experiment was conducted in the machine manufactured by Harbin Institute of Technology (HIT). It consists of pressure intensifier, closing machine, three servo cylinders and computer control system. The tooling is composed of left punch, right punch, upper die, lower die and transverse movable die.

2.4 Samples

The internal pressure plays an important role in the shear hydro-bending process. Two internal pressures were chosen to study the effect on the microstructure of the shear-bent tube. Fig. 2 shows the successfully formed tubes with the internal pressures of 15.2 and 38.0 MPa. Four corner zones are investigated with the EBSD technique, as shown in Fig. 3.

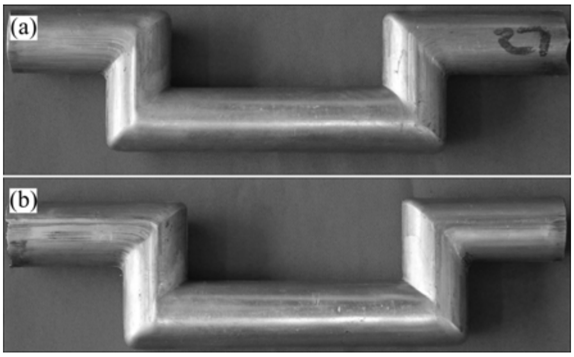

Fig. 2 Shear hydro-bent tube under different internal pressures: (a) 15.2 MPa; (b) 38.0 MPa

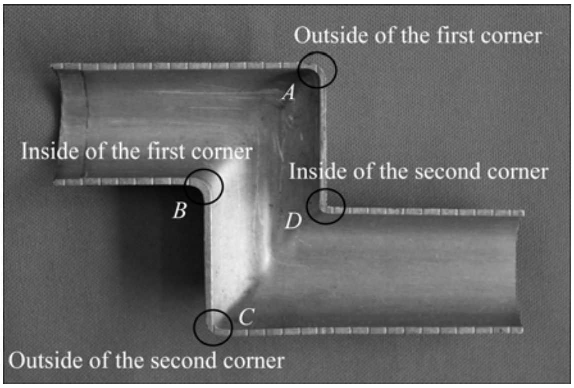

Fig. 3 Schematic diagram of sample: *A*—Outside of the first corner; *B*—Inside of the first corner; *C*—Outside of the second corner; *D*—Inside of the second corner

The samples were taken from the centerline of the shear hydro-bent tube. Zone *A* is the outside and zone *B* is the inside of the first corner of the tube. Zone *C* is the outside and zone *D* is the inside of the second corner of the tube. In order to map subgrain boundary misorientations and other substructures, a step size of 6μm was chosen. The dot density of each measured area is 150×150.

3 Results and discussion

3.1 Microstructure of undeformed tube

The grain distribution of the annealed original tube is shown in Fig. 4. The diameters of the grains are about 100 μm. The grain size is uniform and all of the grains are approximately equiaxed grains. The grain boundaries are distinct.

3.2 Microstructure of shear hydro-bent tube under internal pressure of 15.2 MPa

The grain distributions of the first corner are shown in Fig. 5. The tube was obtained under the internal pressure of 15.2 MPa.

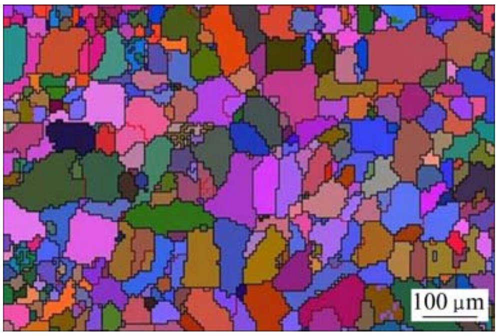

Fig. 4 Grain map of undeformed annealed tube

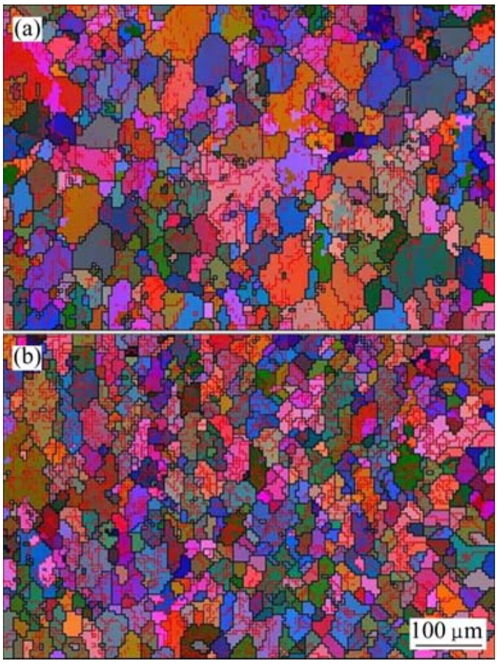

Fig. 5 Grain map of tube formed at 15.2 MPa in the first corner: (a) Outside; (b) Inside

The grain size at outside is about 100 μm. It is similar to that of the undeformed tube, but the grain boundaries become indistinct. The grain size is 30−50 μm at inside, which is smaller than that obtained in the outside corner. Compared with the undeformed tube, the grains are refined during the shear hydro-bending process. The plastic deformation of shear hydro-bending breaks the big grain into subgrain with small angle boundary. Subgrain is elongated along a certain direction whose width is micron or submicron. Then the equiaxed grains with large angle boundary appear and subgrains disappear. The microstructure is mostly equiaxed grain with large angle boundary.

The stress and the strain states are related to the deformation of the corner zone, especially at inside corner. Not only the compressive stress, but also the shear stress influences the deformation.

In the first corner zone, the circumferential and axial stress states at outside corner are both tensile. The radial strain state is negative and the axial strain state is positive. The radial stress state is compressive and the circumferential and axial stress states at inside are both tensile. The radial and axial strain are both negative. Besides, there are shear stress and strain existing in the inside area, as shown in Fig. 6. The stress and the strain states of the second corner are the same as those of the first corner zone.

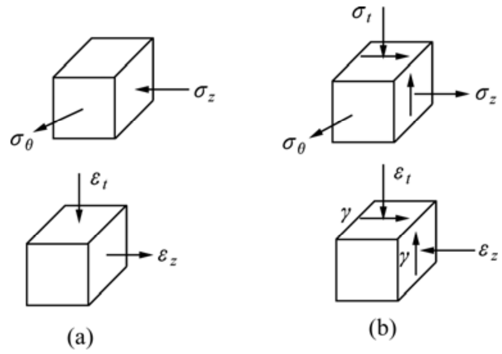

Fig. 6 Stress and strain of corner zone: (a) Outside corner; (b) Inside corner

It can be seen that in the first corner, the deformations include bending and bulging at outside and bending and shearing at inside. The deformation in the second corner zone is similar to that in the first corner, but there is no axial feeding during the shear hydro-bending process.

The grain distributions of the second corner are shown in Fig. 7. It is similar to that of the first corner. The grain size is 50−70 μm at outside, but they are

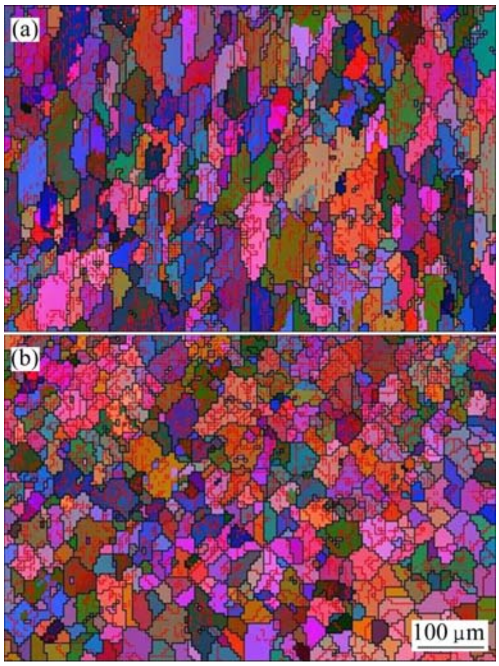

Fig. 7 Grain map of tube formed at 15.2 MPa in the second corner: (a) Outside; (b) Inside

apparently elongated. The deformation includes bending and bulging without axial feeding. So the grains are elongated more apparently than those of the first corner. The grain size is 30−50 μm at inside, which are smaller than those obtained at outside corner.

3.3 Microstructure of shear hydro-bent tube under internal pressure of 38.0 MPa

Figure 8 shows the grain distribution of first corner of the formed tube which is obtained under the internal pressure of 38.0 MPa.

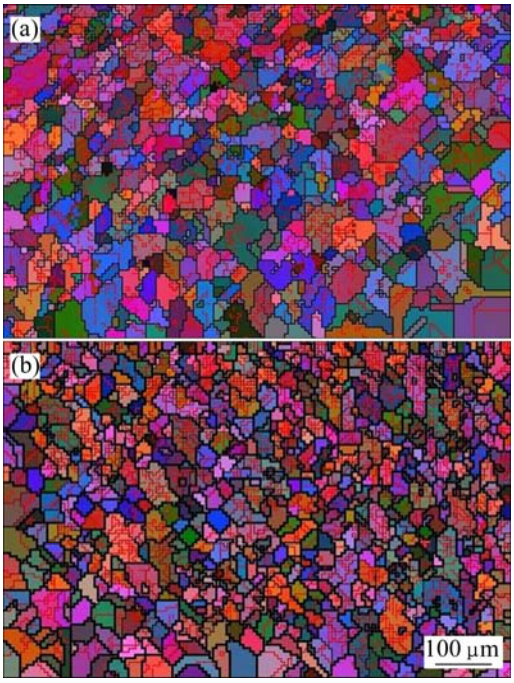

Fig. 8 Grain map of tube formed at 38.0 MPa in the first corner: (a) Outside; (b) Inside

The grain size of the outside is uniform and the diameters are mostly 30−50 μm and the substructure is observed. The grain size of the inside of the first corner is uniform and the diameters are mostly 10−20 μm, which are smaller than those obtained at outside corner. With the internal pressure increasing, the compressive stress and the shear stress at inside corner increase, so the plastic deformation is severe and the strain capacity is large. The severe plastic deformation breaks the big grain into subgrain with small angle boundary.

Figure 9 shows the grain distribution of the second corner of the tube under the internal pressure of 38.0 MPa. It is similar to that in the first corner zone. The diameters of the grains are mostly 30−50 μm at outside and the substructure is observed. The diameters are mostly 10−20 μm at inside, which are smaller than those obtained at outside.

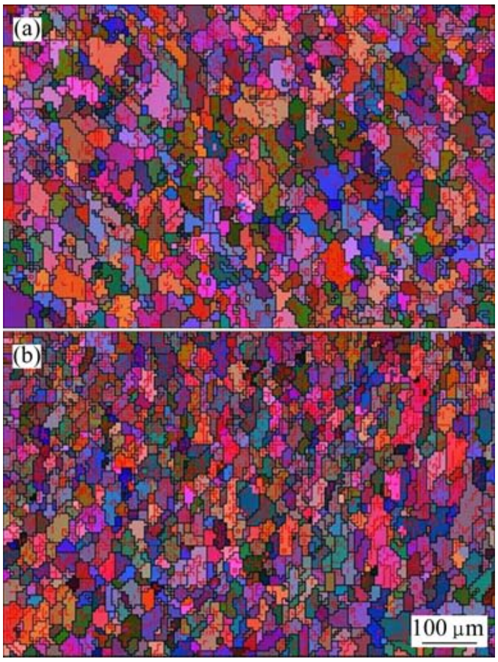

Fig. 9 Grain map of tube formed at 38.0MPa in the second corner: (a) Outside; (b) Inside

4 Conclusions

1) The stress and the strain states influence the microstructure of the corner zone. The stress state of the inside corner is different from that of the outside. Besides, there exist shear stress and strain in the inside area.

2) The microstructures of two corner zones are different. The grain size is becoming small with the internal pressure increasing in the corner zones. The grain size of inside is smaller than that of outside even if the internal pressure is the same.

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内压对 5A02 铝合金充液剪切弯曲管微观结构的影响

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摘 要：为了研究剪切变形对微观组织的影响，采用电子背散射衍射方法研究铝合金剪切弯曲管的微观组织特征。分析不同内压对外侧圆角和内侧圆角微观组织的影响。结果发现：未变形管材的晶粒尺寸为 100 μm；在内压为 15.2 MPa 时，变形管材的外侧弯角区域晶粒尺寸为 50~100 μm，而内侧弯角区域晶粒细化到 30~50 μm；当内压达到 38.0 MPa 时，晶粒进一步细化，在变形管材的外侧弯角区域晶粒尺寸达到 30~50 μm，而内侧弯角区域晶粒细化到 10~20 μm。由此可知，剪切变形对两圆角区域的微观组织有着重要的影响，随着成形压力的提高，晶粒尺寸逐渐细化。由于内外侧不同的变形程度，即便成形压力相同，内侧晶粒尺寸也明显小于外侧的。

关键词：内高压成形；微观结构；电子背散射衍射；管材；铝合金

(Edited by HE Xue-feng)