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# Influence of heat treatment conditions on bending characteristics of 6063 aluminum alloy sheets

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**Abstract:** Bending deformation behaviors of solution treated (ST), natural aged (NA) and T6 tempered 6063 aluminum alloy sheets were studied by three-point bending tests. The changes of bending force, interior angle, bending radius and sheet thickness in the fillet region were analyzed by experimental measurements and numerical simulations. The results showed that the bending characteristics were strongly dependent on the heat treatment conditions. The T6 alloy sheets were bent more sharply and local plastic deformation occurred severely in the fillet region. However, the ST and NA alloy sheets exhibited relatively uniform bending deformation and large bending radius. The bending force of T6 alloy was the highest, followed by the NA alloy and that of the ST alloy was minimum. After unloading, as compared with the ST and NA alloys, the springback of T6 alloys was markedly larger. The aging time showed a positive sensitivity on the springback and non-uniform bending deformability. The bending characteristics are attributed to the combined effects of yield strength, yield ratio and coefficient of neutral layer.
**Key words:** 6063 aluminum alloy; three-point bending; heat treatment conditions; bending characteristic; yield ratio; simulation

## 1 Introduction

Lightweight is the most effective way to realize the sustainable development of transportation industry. Aluminum alloys are suitable for weight-reduced components due to their high specific strength, stiffness and energy absorption [1]. Taking into account of the requirements in terms of aerodynamics, structural mechanics and aesthetics, automotive components are generally needed to bend into a certain curvature [2], which proposes a higher requirement on the quality of curved products. Aluminum alloys usually suffer from poor bendability at room temperature, accompanying with defects such as springback, cross-section deformation and surface cracking [3−5], which severely restricts the application of aluminum alloys in the automobile body. The microstructures, mechanical properties exhibited by aluminum alloys are significantly influenced by the hot treatments [6,7]. Accordingly, their bendability would also change.

SNILSBERG et al [8] proposed that extruded aluminum alloys profiles showed better bendability when the bending axis was parallel to the extrusion direction, than that when it was perpendicular to the extrusion direction, for both recrystallized and fibrous grain morphologies. ZHANG et al [9] investigated the effects of material parameters on springback of 5052 aluminium alloy sections with hat profile in rotary draw bending. LIU et al [10,11] investigated the springback behaviors of the age-hardened 2196-T8511 and 2099-T83 Al−Li alloys profiles under displacement controlled cold stretch bending. PAULSEN and WELO [12] investigated the effect of material behaviour on the springback and cross section deformation in stretch bending of aluminium profiles by finite element (FE) simulations. LLOYD et al [13] assessed the bend performance of the heat treatable skin alloy AA 6111 and the non-heat treatable structural alloy, AA 5754 by the cantilever bend tests. LĂZĂRESCU [14] investigated the rotary draw bending

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of aluminum alloy tubes with internal fluid pressure by FE simulations and experiments. KIM and KOÇ [15] investigated the effect of temperature gradients on the final part quality in warm forming of lightweight materials by FE analyses. GRÈZE et al [16] investigated the influence of the temperature on residual stress and springback in AA5754-O aluminium alloy by split-ring tests.

To date, the bending deformation behaviors of many aluminum alloys during the bending process were investigated. However, no systematic study on the role of heat treatment conditions on the bending characteristics can be found. The aim of this study is to investigate the influence of material states on bending characteristics of heat-treatable 6063 aluminum alloys at room temperature by three-point bending tests combining with numerical simulations. A 3D-FE model for three-point bending process was established based on the LS-DYNA software package. The changes of bending force, interior angle, bending radius and sheet thickness in the fillet region were analyzed rigorously. Finally, the deformation mechanisms underlying bending characteristics of different materials have been revealed.

## 2 Experimental

### 2.1 Materials and heat treatment

The material used in this study was the commercial 6063 aluminum alloy. The chemical composition is shown in Table 1. The sheet specimens were taken from a hollow extruded profile with a thickness of 3 mm, which had been treated with natural aging. To investigate the effect of material states on the bending characteristics, for the ST alloys, the original NA alloys were heat treated at 535 °C for 1 h to make sure that the Mg and Si were in solid solution as much as possible, and then cooled rapidly enough to hold the constituents in solution. For the T6 temper, the ST alloys were heat-treated at 180 °C for 2 h and 6 h, respectively.

**Table 1** Chemical composition of 6063 aluminum alloy (mass fraction,%)

| Si | Mg | Fe | Cu | Mn | Cr | Zn | Ti | Al |
|---|---|---|---|---|---|---|---|---|
| 0.45 | 0.65 | 0.30 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | Bal. |

### 2.2 Tensile test

The tensile test was widely used to provide basic design information on the strength and ductility of materials. Standard tensile specimens with gauge length of 46 mm and gauge width of 12.5 mm were machined from the extruded profiles. Figure 1 shows the detailed dimensions of the tensile specimen. In tensile test, the specimen was placed between two fixtures called “grips” which clamp the specimen. Then, the tensile test was carried out at a tensile rate of 2 mm/min by an Instron-type electromechanical machine. The tensile force versus displacement data was recorded automatically.

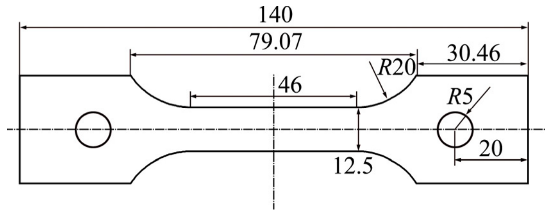


**Fig. 1** Dimensions of tensile test specimen (unit: mm)

### 2.3 Three-point bending test

The three-point bending tests were performed using a universal mechanical testing machine, INSTRON (Model 1342) with a computer control and data acquisition system, as shown in Fig. 2. The apparatus has a loading capacity of 250 kN and bending stroke of ±50 mm. A 2D schematic of mechanics model is illustrated in Fig. 3, where $L$ and $t$ denote the length and thickness of the specimen, respectively. The specimen sizes of sheet were 160 mm × 20 mm × 3 mm. The side cylindrical supporters were laid on the floor symmetrically. The indenter had the same diameter as that of these two side cylindrical supporters ($r$=5 mm) to prevent localized indentation in the upper face of the sheet specimen. The support span $S$ in the three-point bending rig was set to be 120 mm. The bending experiments were carried out at three different material states. During bending tests, the specimen was symmetrically placed in the middle of the supports. In the beginning, the specimen was contacted with the indenter at the middle line only. The direction of bending moment was perpendicular to the longitudinal direction of the specimen (i.e. the $Y$ direction in Fig. 3). All the specimens were deformed to a deflection of 30 mm at a constant speed of 10 mm/min (i.e. quasi-static). Thus, the bending time was about 3 min for each specimen. During bending test, the bending force versus indenter stroke data can be acquired and recorded automatically by the BLUEHILL software incorporated with UTM machine.

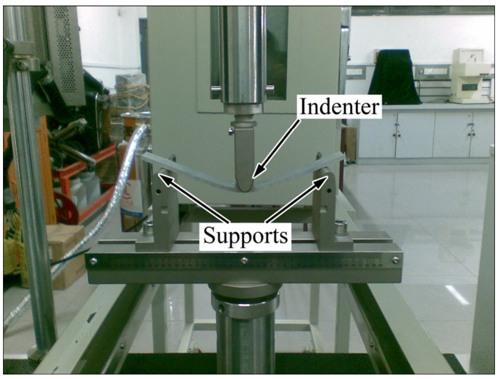


**Fig. 2** Experimental apparatus for three-point bending test