Materials Characterization 129 (2017) 88–97

Contents lists available at ScienceDirect

Materials Characterization

journal homepage: www.elsevier.com/locate/matchar

Microstructure difference of 5052 aluminum alloys under conventional drawing and electromagnetic pulse assisted incremental drawing

Jinxiu Fang[a,*], Jianhua Mo[b], Jianjun Li[b]

[a] School of Metallurgical Engineering, Anhui University of Technology, Maanshan 243002, China
[b] State Key Laboratory of Material Processing and Die & Mould Technology, Huazhong University of Science and Technology, Wuhan 430074, China

ARTICLE INFO

Keywords:
Electromagnetic pulse-assisted incremental drawing
Conventional drawing
Aluminum alloys
Micro hardness
Dislocations

ABSTRACT

In the electromagnetic pulse assisted incremental drawing (EMPAID) process, the sheet metal was alternatively deformed under quasi-static and high speed conditions, whereas the formed cylindrical cup height increased remarkably. In order for the sheet metal plastic properties increase reasons and the deformation mechanism to be understood, in this work, the deformation behavior and the microstructure evolution of 5052 aluminum alloys were compared with the conventional drawing by micro hardness analysis, the electron back scattering diffraction (EBSD) observations and the transmission electron microscopy (TEM) studies. The results demonstrated that under the EMPAID, the cylindrical cup micro hardness exceeded the conventional drawing micro hardness. The EBSD observations displayed that in the EMPAID process, the grain shapes apparently changed: among these observations, under the uniaxial tensile stress, the grains in the cylindrical wall region were elongated; whereas in the region of the die corner and the end of the flange, the grains became flat under the axial and radial compressive stress. The TEM observations demonstrated that the plastic deformation mechanism of the 5052 aluminum alloys was the dislocation-slip under both conditions. Furthermore, the dislocation density significantly increased subsequently to EMPAID, whereas the corresponding distribution was quite uniform. Also, the slip bands and the equiaxed grains also appeared in the local area and consequently the plasticity of the formed part could be improved.

1. Introduction

In recent years, with the rapid development of aviation, aerospace, electronics, automobile and arms industries, the energy saving and emission reduction standard and the safety performance requirement gradually increased. Therefore, it was urgent for the light weight forms of modern structural design to be sought. Through the lightweight high strength materials [1,2], such as the aluminum alloy, the lightweight character is achieved. Compared to the traditional steels, the aluminum alloys have the advantages of low density, high specific modulus, specific strength, good corrosion resistance, fatigue strength, excellent impact resistance, formability and possible recyclability [3–6]. In contrast, the aluminum alloy formability was poor at room temperature, when the conventional drawing technology was utilized, the metal flow was non-uniform. In this case it was easy for problems such as cracks and wrinkles to occur; subsequently the forming limit was quite lower compared to the steel forming limit. In addition, the aluminum alloy elastic modulus was only 1/3 of the steel elastic modulus. Following unloading, the workpiece easily displayed a higher rebound and distortion, whereas it was difficult for the forming precision to be accurately controlled [7,8]. Compared to other material processing technologies, the conventional drawing process still had the characteristics of high material utilization rate, low cost, high production efficiency and easy automation. Therefore, the modification and improvement of this forming process has attracted significant attention from researchers.

Vohnout and Daehn [9,10] proposed a new forming method, the Matched Tool-Electromagnetic Hybrid Sheet Forming (MT-EM), and executed a series of innovative researches. In this method, the traditional stamping tooling is utilized in the sheet metal pre-forming to certain optimum extent. Subsequently, the electromagnetic coils, which were embedded in the tool halves, were utilized in the tight corners and micro features forming accomplishment. The feasibility of this technology was proved by successfully an aluminum alloy inner-door panel forming. The formed door panel shape was similar to the desired shape, the edge lines were clear and no apparent wrinkles existed at the edges. In addition, the plane strain values in excess of 25% were observed on the electromagnetically reformed panel, which exceeded the plane

* Corresponding author at: No. 59 Hudong Road, Maanshan 243002, China.
E-mail address: jinxiufang@hust.edu.cn (J. Fang).

http://dx.doi.org/10.1016/j.matchar.2017.04.035
Received 8 October 2016; Received in revised form 21 April 2017; Accepted 27 April 2017
Available online 29 April 2017

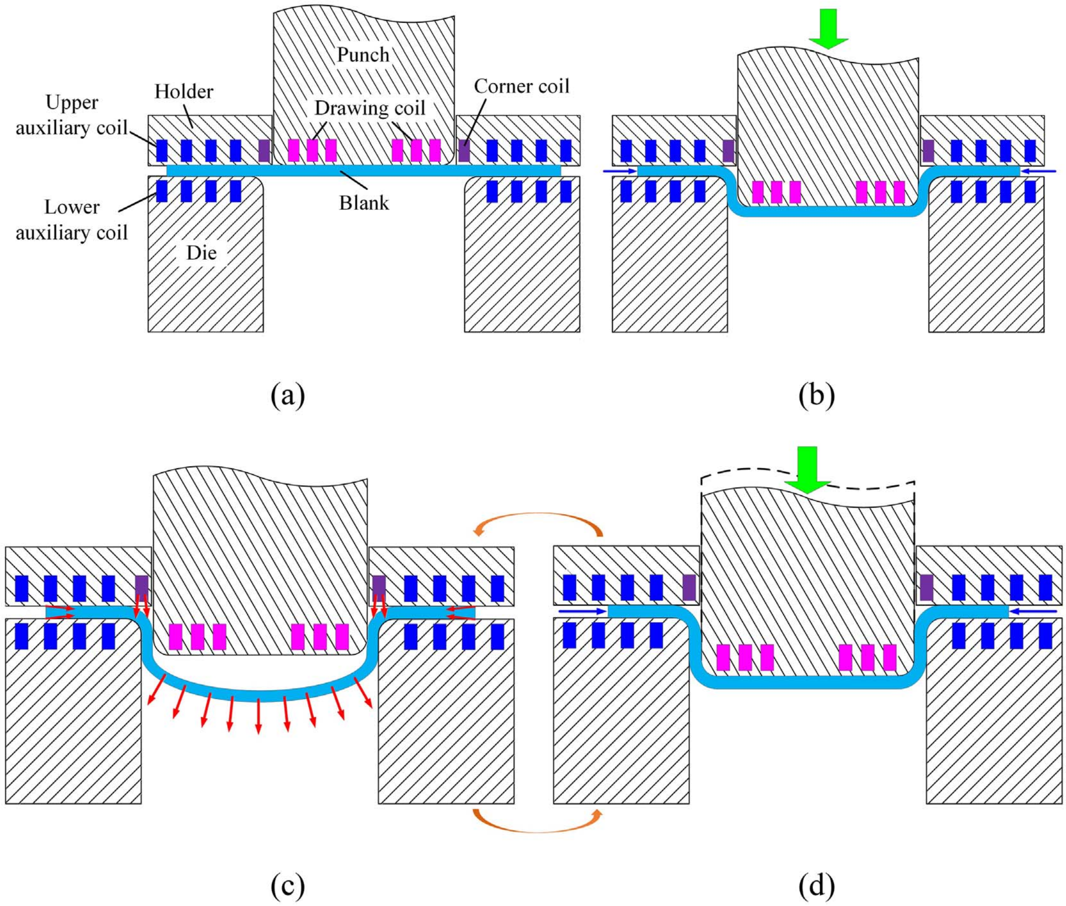

Fig. 1. Schematic showing the EMPAID process. (a) The initial state, (b) the pre drawing process, (c) the discharging process, and (d) the micro shaping process.

strain value of the AA6111-T4 aluminum alloy under the quasi-static condition. This experiment successfully demonstrated that it was feasible to improve the aluminum alloy formability by the incorporation of electromagnetic forming technology and conventional drawing technology.

Furthermore, Shang and Daehn [11–14] developed a new technology, the Electromagnetic assisted sheet metal stamping (EASMS). By multiple low energy discharge, the single large energy discharge was replaced, effectively controlling the workpiece strain distribution. Subsequently, the stamping part formability was improved. The basic idea of this technology was: embedding of electromagnetic coils at proper positions into the stamping molds, whereas during forming, firstly the electromagnetic pulse with a predefined energy was supplied to the coils and deformed the sheet metal to produce a stretched "bubble"; consequently the traditional drawing molds were utilized to flatten the "bubble", the discharge and mold advancing operation executions were repeated until the failure of the metal sheet. A series of experiments conducted on aluminum alloys proved that the EASMS could significantly increase the material formability.

Compared to the conventional drawing, the plasticity improvement was mainly attributed to the high speed deformation caused by the magnetic force. Under high speed deformation, the yield and flow stresses of the material were quite different from the stresses under the quasi-static condition. Subsequently, the deformation behavior and mechanism of the material was changed highly. The dynamic response of the material was closely related to the microstructure evolution.

Liu et al. [15] compared the plastic deformation behavior and the microstructure evolution under the dynamics processes to the quasi-static condition corresponding behavior and evolution. The results demonstrated that in both forming processes, the sheet metal plastic deformation mechanism was the dislocation-slip. Also, under high speed deformation, due to the shock effect, significantly denser dislocations were generated and the corresponding distribution was quite uniform. In contrast, the dislocation cross-slip tendencies increased. Yan et al. [16] through the uniaxial tension tests analyzed the electropulsing effect on the deformation behavior, texture and microstructure of 5A02 aluminum alloys. The microstructural characterization demonstrated that as the electropulsing intensity increased, the slipping transformed from planar slip to wave slip. Li et al. [17] compared the deformation behavior of 5052 aluminum alloys under the electromagnetic forming process to the mechanical deformation behavior. These studies demonstrated that in the mechanical deformation process, the deformation mechanism of 5052 aluminum alloys was the planar slip, whereas in the electromagnetic forming process, the deformation mechanism was dominated by a wavy slip. Yan et al. [18] executed dynamic tensile/compressive experiments for 5A06 and 5A02 alloys, discovering that as the strain rate increased, both alloys displayed notable work hardening and serrated flow stress-strain curves. In addition, in the high velocity deformation process, the ductility of both alloys was enhanced. Similar experimental results were also observed in the dynamic tensile/compressive tests of 5A02-O aluminum alloys by Ma et al. [19].

In this paper the electromagnetic pulse assisted incremental drawing was utilized [20,21] in the aluminum cylindrical cup forming, where the sheet metal was alternately deformed under quasi-static and high speed conditions, whereas the limit drawing height of the cylindrical cup was significantly increased compared to the cup of the conventional drawing case. Therefore, the deformation behavior and deformation mechanism of the material changed highly from the behavior and mechanism under the quasi-static condition. In order for the sheet metal deformation mechanism in the EMPAID process to be demonstrated, the aluminum sheet microstructures were system-