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The Effects of Annealing Parameters on Earing for Aluminum Alloy

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ABSTRACT:

The aim of this study is to investigate the effect of annealing parameters on the earing problem in deep drawing of AA 1060 alloy. It is also objected to minimize the percent earing by changing annealing parameters. In experiments, AA 1060 aluminum sheets with 1,5 mm thickness were annealed at different conditions as follow: temperatures were changed from 225^{o}C to 400^{o}C at 10 different points, annealing time were changed from 0 to 60 minutes at 5 different periods. Then heat-treated specimens were tested at Zwick tensile test machine. From test results, percent earing values were determined. After comparing all test results each other, it was seen that the percent earing was determined as 8,49 for untreated AA 1060 alloy but the percent earing was found as 3,62 for specimens which were annealed at optimum treating parameters as 300^{o}C temperature and 30 minutes time. An obvious reduction was determined in percent earing. Finally, it was determined in this study that earing-anisotropy ratio relationship given by some researchers for different aluminum alloys in invalid for AA 1060.

Keywords: *AA 1060, Annealing, Earing*

1. INTRODUCTION

AA 1060 aluminum alloy is widely used in electrical and technical industry because of its at least 99.00 percent purity. In spite of its high corrosion resistance, good heat conduction properties and high workability, strength of AA 1060 is low. In deep drawing processes, some problems occur. The sources of the problems may be explained as fallow: deep drawing machine properties die and punch design and mechanical properties of used sheet metal. There are lots of parameters which cause the same deep drawing problem at the same time. Therefore generally, it is impossible to determine which parameter has an effect on the problem, at that time. In spite of this, according to the main reasons, deep drawing problems may be divided into two main groups. The first group is machines and process parameters. Used sheet-metal properties may be accepted as a second group [1]. In this study, the second group problem sources were investigated.

Earing: Earing is the formation of a wavy edge on the top a drawn cup. Every wavy part of the edge of cup is called ear. This problem is often-seen deep drawing problem. Although, after deep drawing two, four, six or eight ears may be formed. Four-ear formed cup have been seen most widely [2,3,4,5]. According to the direction of ears to the rolling direction, earing can be divided into two types [6,7,8].

i) 0^o, 90^o earing
ii) 45^o earing.

The main reason which causes earing is anisotropic characteristics of blank sheet which has crystallographic texture. The direction and rate of crystallographic texture effect the direction and dimension of ears [8]. Greater ears means to use much more sheet material and additional edge cutting process [9]. Although formation of ear depends on the average anisotropy, ear shape and direction is a function of the planar anisotropy and earing can be directly correlated with the planar anisotropy [3,10,11,12,13].

Anisotropy behavior of materials has most significant effect on deep draw ability of sheet. Metals have undergone extensive plastic deformation, show anisotropy behavior in mechanical properties and plastic deformation on different directions due to preferred grain orientation at structure. Even in the case of untextured metals showing isotropic or almost isotropic yielding behavior, ductility can be very anisotropic [14].

2. EXPERIMENTAL STUDIES

In this study, cold-rolled AA 1060 aluminum sheets 1,5 mm in thickness produced by Etibank Seydisehir Aluminum Corp. were used aluminum sheets which were heat-treated between 225^oC-400^oC temperature range at different annealing durations as 0, 30, 45 and 60 minutes. Then, according to TSE 138, tensile test specimens were prepared from annealed sheets at the directions which make 0^o , 45^o and 90^0 angle to rolling direction tensile test specimens were tested at Zwick made testing machine. Using tensile test results anisotropy values were determined at 0^o , 45^o and 90^0 directions. On the other hand, deep drawing specimen sheets 55 mm inner diameter were prepared and cups 30 mm inner diameter were produced by deep drawing. The purpose of this small scale in deep drawing process was to measure earing nature of the tested sheets. To be able to determine percent earing, equation (1) was use.

$$\%\ Earing = [(H_{1\,ave} - H_{0\,ave}) / H_{1\,ave}] * 100 \quad (1)$$

Where; $H_{1\,ave}$: Average ear height

$H_{0\,ave}$: Average ditch height

Calculated anisotropy values from test results depending on the annealing temperatures were given in table 1. Changing in Erichsen depth values with annealing temperatures are shown in Figure 1.and Figure 2. As a second parameter, annealing time is also given in that figure. The relationships between percent earing and annealing temperature were plotted in Figure 3. and Figure 4. To be able to compare the results, there different curves were plotted in the same figure.

Figure 1. *Erichsen test results*

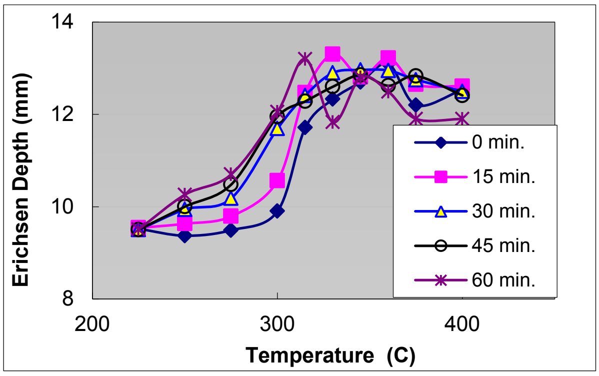

Figure 2. *Annealing temperature and Erichsen depth relationship for AA 1060 alloy.*

Table 1. *Calculated anisotropy values from test results depending on the annealing temperatures for AA 1060.*

Annealing Temp. (°C)	Annealing Time (min)	R_o	R_{45}	R_{90}	R_{ave}	ΔR
225	0	0,440	2,130	1,060	1,440	-1,380
	15	0,470	2,370	1,990	1,550	-1,640
	30	0,690	2,330	1,430	1,695	-1,270
	45	0,600	2,300	1,400	1,650	-1,300
	60	0,370	1,590	1,340	1,223	-0,735
250	0	0,620	1,510	1,150	1,198	-0,625
	15	0,480	1,440	1,530	1,223	-0,435
	30	0,580	0,910	1,590	0,998	-0,175
	45	0,600	1,500	1,590	1,298	-0,405
	60	0,610	1,560	1,940	1,418	-0,285
300	0	0,420	1,200	1,520	1,085	-0,230
	15	0,620	1,700	0,800	1,205	-0,990
	30	0,710	0,520	0,700	0,613	0,185
	45	0,780	0,470	0,800	0,630	0,320
	60	0,840	0,410	0,860	0,638	0,440
360	0	0,800	0,600	0,770	0,683	0,185
	15	0,910	0,440	1,010	0,708	0,520
	30	0,800	0,720	1,010	0,813	0,185
	45	0,990	0,760	0,880	0,847	0,185
	60	0,890	0,590	1,060	0,783	0,385
400	0	0,950	0,550	0,810	0,715	0,330
	15	0,880	0,630	0,880	0,755	0,250
	30	1,000	0,560	0,780	0,725	0,330
	45	0,870	0,470	0,820	0,658	0,375
	60	0,990	0,630	1,030	0,820	0,380

Figure 3. *Earing test results.*

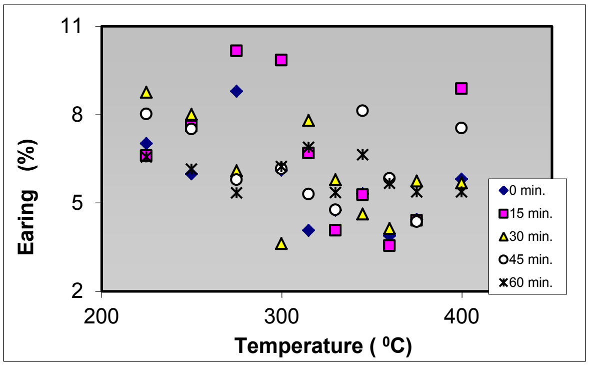

Figure 4. *Annealing temperature and % earing relations for AA 1060 alloy.*

3. RESULTS

For AA 1060 aluminum sheets, foolowing results were concluded.

1. Erichsen depth which is an important indicator of deep drawability increases with the annealing temperatures. It was determined that the maximum value of Erichsen depth is 23.09 mm for 360^{o}C annealing temperature and 0 minute annealing time.

2. High amount of deformation takes place in 0 and 90-degree respect to rolling direction and in this area thickness of cup wall is less than bottom of cup. Minimum cup height is observed at 45 degree.

3. Average vertical anisotropy value (R_{ave}) for AA 1060 was given as 0.74 in some research reports. These values for aluminum alloys are at 0.60 – 0.85 range. R_{ave} value shows the deep drawing characteristic of material. If $R_{ave} > 0.85$, the deep draw ability of materials is good and if $R_{ave} < 0.60$, the deep draw ability of materials is poor [14,15]. In this study, R_{ave} values were determined between 1.198 and 0.658 range. These results show that determined R_{ave} values indicate good deep draw ability of tested material.

4. It was determined that percent earing values decrease gradually for temperatures higher than 300^{o}C. If the earing value for 300^{o}C was compared to the earing value for 225^{o}C, 35 percent used materials was saved. This result means that in mass production used material saving will be increased. In this study, it was also concluded that percent earing-anisotropy rate (R_{ave} /ΔR) relationship for aluminum alloys which was given by some researches[10] is not valid for AA 1060 alloy which has 99.60 percent purity.

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