Effect of Annealing Treatment on the Anisotropy Behavior of Cold Rolled Stainless Steel 304 Sheets

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Abstract

Anisotropy of materials has harmful effects during deep drawing operations and reduce it will strongly enhance the productivity and quality of deep drawing yields. In this work the effect of annealing treatment on texture and anisotropy behavior of cold rolled stainless steel 304 sheets were investigated. Uniaxial tensile test samples cut at 0o, 45o and 90o to the rolling direction were prepared in order to measure the anisotropy parameters (normal anisotropy, r_n, and planar anisotropy, Δr). Two annealing temperatures (1050, and 1150) °C were used to study their effects on anisotropy behavior. The results show that the normal anisotropy value of annealed samples at 1150°C increases by (31%) as compared to the received samples. This indicates that the annealed samples at 1150 °C have the highest formability. Also, results show significant reduction (about 88.7%) in planar anisotropy value for 1150°C annealed samples. This gave rise to an increase in deep drawing yield.

Keywords: anisotropy, annealing treatment, stainless steel 304.

1.Introduction

Nowadays, cold-rolled stainless steels sheets have been increasingly utilized in various industries like production of domestic appliances and in automotive industry because of its good formability, excellent strength, and resistance to corrosion. However, because of the microstructural complexities, like the formation of different textures, arising during the rolling of stainless steels and this induce the anisotropic behavior of cold-rolled stainless steel [1, 2]. Preferred grain orientation which forms during rolling processes is the main cause of anisotropy in materials. Anisotropy in the metal leads to inverse effects on subsequent sheet metal forming processes, especially deep drawing operation [3]. Where, directionality in properties and rolled texture usually give rise to excessive earring, tears, and breakout in parts production by deep drawing and extrusion processes. Drawn cups earing are due to vary values of plastic strain ratio at different directions [4]. After deep drawing process, this irregularity (ears) at the top of cups must be eliminated which result in reduce of the process yield and increase in metal waste [5]. Large anisotropic properties lead to higher ear and then reduce in the efficiency of the deep drawing process. Material anisotropy is affected by many factors, grain geometry, rolling conditions, subsequent heat treatment, etc. Many works have been done for evaluation material anisotropy in sheet metal during rolling process.

Soh et. al. [6], optimized some parameters (heat treatment conditions, conditions of plastic deformation (cold work rate, final thickness), the composition of plate, and no. of passes during rolling process) which affected the rolling of aluminum alloy. They show that the anisotropy index can be reduced with increase the thickness of sheets in range from (1.2-2.8) mm. He at el [7], examined the texture of Mg-3Al-Zn alloy with addition of 3% wt Li. They found that the introducing specific twins in alloy have an important and effective role on texture modification of alloy during annealing treatment. Tang et al [8], found that the Magnesium AZ31 sheet produced by cross rolling (CR) (process in which the rolling direction was changed by 90o after each rolling pass) has low r value (close to 1) as compared to those produced by conventional unidirectional rolling (UR), which leads to enhancing the drawing capability. Influences of annealing conditions on material anisotropy behavior of Mg alloy sheets were evaluated by Del Valle and Ruano [9]. They reveal that the thermal treatment lead to noticeable reducing in material anisotropy with grain coarsening. Also, they found that

the annealing treatment produce a slight change in the basal texture.

Although, there are many works have been done for evaluation material anisotropy in sheet metal during rolling process. However, there have been little efforts focused on evolution the anisotropy behavior of Stainless steels alloys. Stainless steels have high demand on the deep drawing process; however, it shows serious earing in production.

In this study, the effects of annealing treatment on anisotropy parameters of cold-rolled stainless steels 304 sheets were studied. Two annealing temperatures (1050, and 1150) °C were used for this purpose. Several uniaxial tensile tests were performed on annealed and as- received samples at different angles (0°, 45° and 90°) respect to the rolling direction (RD), to determine the r-value required for this investigation. Anisotropy parameters (normal anisotropy, r_n, and planar anisotropy, Δr) of all samples were measured and compared to identify the optimal conditions which result in minimum earing.

1.1 Characteristics of Anisotropy

1.1.1 Normal Anisotropy

Many characteristic values are utilized as a measure of material anisotropy. r-value or vertical anisotropy r is the ratio of the logarithmic change of strain in the direction of the sheet width (true width strain) to the change of strain in the direction of the sheet thickness (true thickness strain) [10, 11]:

$$r = \frac{strain_w}{strain_t} = \frac{\epsilon_w}{\epsilon_t} \qquad (1)$$

Where ϵ_w is the strain in the direction of width, and ϵ_t is the strain in the direction of thickness. Isotropic material has a value of r = 1. Material that has a r-value > 1, has high resistance to plastic deformation in the direction of the sheet thickness. The r-value is not constant in a sheet plane, but depends on the angle from the rolling direction. The value of vertical anisotropy r is depends also on the previous treatment and the material composition, since the r-values change for the different directions, the average vertical anisotropy (normal anisotropy) r_n can be used and calculated [10, 11]:

$$r_n = \frac{r_0 + r_{90} + 2r_{45}}{4} \qquad (2)$$

Where the index indicates the angle to the rolling direction.

The r_n value characterizes the sheet resistance to thinning during deep drawing process. The lowest r_n value refers to the location in the plane of the sheet with the largest probability of necking. Consequently, r_n values are preferred to be as large as possible.

1.1.2 Planar Anisotropy

Another important measure for the variance of the r-value over the sheet plane is the planar anisotropy Δr [10, 11]:

$$\Delta r = \frac{r_0 + r_{90} - 2r_{45}}{2} \qquad (3)$$

The planar anisotropy value has the significant effect on deep drawing process.

The high values of planar anisotropy lead to unfavorable earing during the deep drawing of axially symmetrical cylindrical cups. Otherwise, when planar anisotropy was zero, no earing occurs in the part. Earing is expected in those directions that have the highest r values. Earing takes place in the 90° and 0° directions for positive Δr values i.e. (Δr > 0). While, for negative values of Δr i.e. (Δr < 0), earing takes place at 45° in respect to rolling orientation.

Generally, for successful deep drawing process, the average vertical anisotropy r_n should be as high as possible, whereas the planar anisotropy Δr should be as small as possible.

2. Materials and Methods

2.1 Research Material

Cold rolled stainless steel 304 sheet with a thickness of 2 mm was used in this work. The chemical composition of the material is listed in Table 1.

Table 1 Chemical composition of stainless steel 304.

Element	Measured Value	Standard Value
C	0.05	≤ 0.08
Mn	1.15	≤ 2
S	0.027	≤ 0.03
Cr	18.2	18-20
Ni	8.6	8-12
Si	0.64	≤ 0.75
N	0.15	≤ 0.12
Fe	balanced	balanced

2.2 Metallographic Practice

The metallographic specimens were prepared by mounting, and grinding using emery paper with grit 220 to 1200 in succession. The ground surfaces of the specimens were polished using diamond paste then were etched

with a solution containing 5 grams of sodium hydroxide (NaOH) dissolved in 100 mL of water for 20 seconds and then dried. The optical Metallurgical Microscope was used to analyze the microstructure of etched surfaces, and observe the change in grain structure.

2.3 Heat treatment

Annealing heat treatments were done on the samples by using muffle furnace. Two annealing temperatures (1050 and 1150) °C were used to heating the samples. The heated samples were soaked for 10 min and followed by cooling in furnace to room temperature.

2.4 Tensile test

The suitability of sheets for deep drawing processes can be evaluated from anisotropy parameters, which are determined from tensile tests. Therefore, experimental tensile tests were conducted and flat specimens with thickness 2 mm were cut at 0° and 45° and 90° with the rolling directions to be used for measure the r-value of used materials. The test procedure was done according to standard ASTM-E517. The dimension and shape of the sample are shown in Figure 1. The anisotropy coefficient (r-value), normal anisotropy (r_n), and planar anisotropy (Δr) can be determined by equations (1-3).
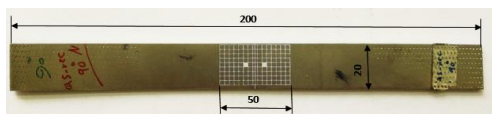

Figure 1: Machined Rectangular Tension Test Specimens, Parallel Strip, for r Determination (all dimension in mm)

2.5 Grid application

Strains to be measured are often very small, and almost the displacement readings are difficult to make with high accuracy. Therefore, a grid was applied on the surface of samples in order to determine strain and displacements components in longitudinal and transverse directions. The dimensions of grid were (50 mm×20 mm) and the length between lines was (1mm) as shown in Figure 2. A photograph picture was taken of the grid network on all samples. The distance between the grid lines on the model was measured by a microscope by keeping the magnification of microscope same before and after loading.
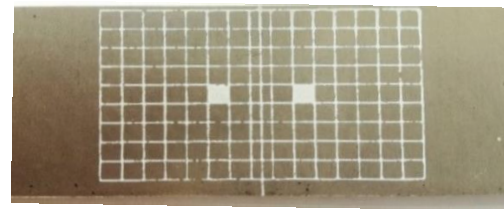

Figure 2: grid for strains and displacements measurement

3.Results and Discussion

3.1 Microstructures

Figure 3 presents the microstructure of the as-rolled and annealing treated stainless steel samples. It is clear from Figure 3 that the microstructure of cold rolled stainless steel 304 samples was modified by heat treatment. For as-rolled case, Figure 3-a, samples have severely deformed microstructure, showing banded structure of grains and inclusions which elongated parallel to the rolling direction. Samples treated at 1050 °C, that illustrate in Figure 3-b, have some deformed grains still remained in addition to small recrystallized grains along boundaries and in most twinned regions. From Figure 3-c, it can be noticed that the full recrystallization is achieved for samples treated at 1150 °C. Also, Figure 3-c indicates that the grain size distribution of sample treated at 1150 °C become more homogeneous than that in samples treated at 1050 °C. Moreover, the grain size in 1150 °C treated samples is obviously smaller and more equiaxed compared to treated samples at 1050 °C. it can be concluded from Figure 3 that the microstructure is hardly affected by increasing the annealing temperature, and the high temperature annealing treatment was led to disappear the banded texture and remove the directionality of grains, in spite of some inclusions still remained as in the as-rolled stainless steel samples.
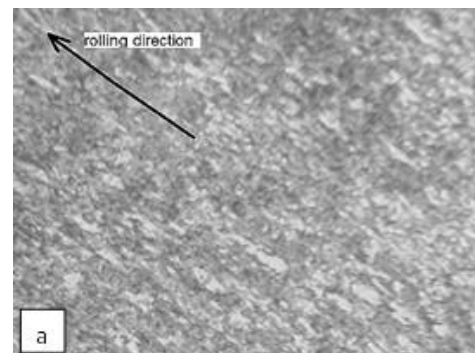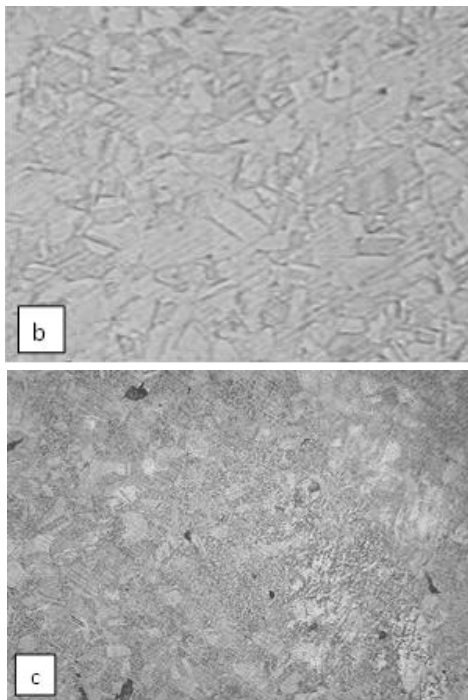
Figure 3: Microstructure of stainless steel samples (a) as rolled (as received); (b) annealed at 1050°C; (c) annealed at 1150°C

3.2 Anisotropy Parameters

The r-ratio values, normal anisotropy (r_n) and planner anisotropy (Δr) of all samples as a function of angle to rolling direction and annealing treatment temperatures are presented in Table 2.

Table 2: Anisotropy parameters for each annealing temperature.

Annealing Temperature (°C)	r-value			Normal anisotropy, r_n	Planner anisotropy, Δr
	0°	45°	90°		
As-received	0.0856	0.1895	0.07	0.13365	-0.1117
1050	0.2118	0.2388	0.0786	0.192	-0.1036
1150	0.1598	0.2232	0.1681	0.19357	-0.0592

It can be notice that the values of r-ratio vary somewhat as a function rolling direction angle, this is related to plastic deformation mechanisms which are strongly affected by presence the slip planes, ability of dislocations to move, and presence of inclusions. It is clear from Table 1 that all values of r_0 and r_{90} in all cases were lower than r_{45}. The larger gap between r_0 and r_{90} as comparison with r_{45}, suggest the high values for planar anisotropy and subsequent large waste in metal through deep drawing processes.

Figure 4 shows the effects of anisotropy on yield strength of stainless steel samples under different annealing temperatures. As well known the yield strength is reduced with annealing treatment. It's clear from Fig. 4 that the anisotropy of as received samples and samples annealing at 1050°C is more noticeable than that of samples annealing at 1150°C. For as received samples, the highest value of yield strength was at an angle of 0 and 90 in respect to rolling direction. Whereas, it was at an angle of 0° for 1050°C annealed samples. On the other hand, it can be seen from Figure 4 that the directionally properties of 1150°C annealed samples was almost removed after annealing treatment. This attributed to disappearance the deformed structure after high annealing temperature and subsequently the directionality of deformed grain was eliminated.
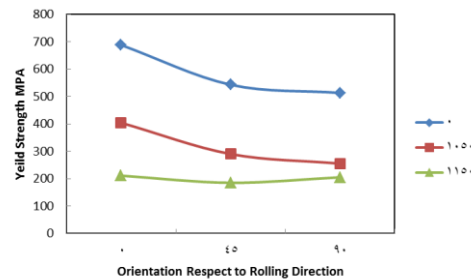

Figure 4: effects of anisotropy on yield strength of stainless steel samples under different annealing temperatures

Figure 5 shows the effects of annealing temperature on normal anisotropy. It can be noticed that the highest value of normal anisotropy occurs for samples annealed at 1150°C, while the lowest was for as received samples. By recalling Figure 3-c it can be notice that the annealing at higher temperature (1150 °C) yields more fine and homogeneous structure than lower annealing temperature. The increasing in the numbers of refine, rounded and recrystallization grains within microstructure of annealed samples result in reduce the anisotropy effects and enhance the normal anisotropy value that leads to good formality properties. This suggests that normal anisotropy of stainless steel samples strongly correlate with annealing treatment and temperature. It is reported in literatures [9, 10] that the annealing and recrystallization treatments play an important role in eliminated

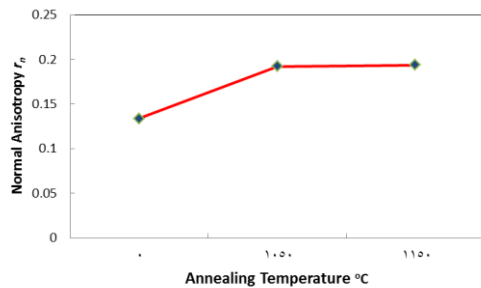the anisotropy affects by modification the grain sizes of materials.

Figure 5: effects of annealing temperature on normal anisotropy

Figure 6 presents the planar anisotropy of as received and annealed stainless steel samples. It follows from Figure 6 that annealing treatment leads to reduce the planar anisotropy value. These results confirmed that the anisotropy depends strongly on the condition under which the samples are deformed and heat treated. Increasing the annealing temperature leads to reduce the disintegration of the recrystallized grains in the samples, thereby, decreasing in planar anisotropy values. This will give rise to an improvement in the deep drawing productivity. The same trend was observed with Tajally and Emadoddin [12] in their research about the evaluation of anisotropy phenomenon of annealed aluminum alloy sheets.
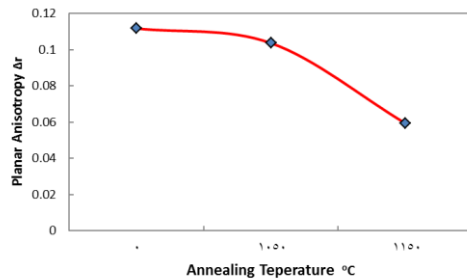

Figure 6: Effects of annealing temperature on planar anisotropy

4.Conclusion

It can be concluding from the results of this work: According to the obtained anisotropy parameters results, the waste of cold rolled stainless steel 304 sheets during deep drawing processes can be strongly eliminated by prior heat treatment. The annealing treatment produces a noticeable modification in the basal texture. The annealing treatment leads to an improvement in formability and reduction in anisotropy of cold rolled stainless steel 304 sheets. The annealed temperature 1150°C brought the best formability (highest value of normal anisotropy) and lowest anisotropic

properties (lower value of planar anisotropy) of cold rolled stainless steel 304 sheets.

5.References

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