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Influence of Heat Treatment on the Drawability and Strain Hardening Index for Low Carbon Al - Killed Steel Sheets

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Abstract

The deep drawing process is one of the most important processes of sheet metal formation, due to it is low-cost, fast, and does not require high skill. The deep drawing is very important in automobile industries, because many parts are produced in this process. For this reason, it is necessary to study all parameters that may affect on the process, including heat treatments, in this work the mechanical properties such as: tensile strength, yield stress, maximum elongation, and strain hardening index for SAE1006 was tested by tensile test which gives a good indication to the extent of the drawability of the metal. Grain size was also measured. All of these tests were conducted in three direction with respect to rolling direction (0°, 45°, 90°) with and without heat treatments. This investigation was done in order to find the effect of recrystallization and stress relief heat treatments on the draw ability of the metal, and the strain hardening index. This work has shown that these heat treatments have a bad effect on mechanical properties required to conduct a deep drawing process because they have increased strength and reduced the ductility. The rupture and wrinkling defects are be in zones defects for the relationship between blank holder force and punch travel distance.

Keywords

Deep Drawing, Recrystallization, Stress Relief, Strain Hardening Index

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1. Introduction

The deep drawing process is the process of converting thin metal sheets into a desired concave shape, using a mold containing a cavity that represents the desired shape [1, 2]. During this process, the sheet metal is subjected to complex stresses to transform it into a concave shape. These stresses are: a lateral compression stress in the circumference of the flange and tensile stress on the walls of the concave part and compression stress normal on the surface of the flange, as a result of these changes in the quality of the stress, the flat plate needs special specifications to be able to reach the final shape successfully [3, 4]. Due to the importance of this process, a large number of researchers studied the properties, variables and applications of this process.

Solution treatment and aging for the optimal stamping properties of the AA6016 deformation aluminum alloy which carried out by using different heat treatment processes, and the effects of drawing speed, blank holder force and other parameters on the formability of sheet metal. The results show that the solution treatment preservation for 40 min at 540°C and pre-aging at 160oC for 10 min is the best heat treatment mode for the stamping formability of AA6016 aluminum alloy, which can effectively improve the forming limit and the formability of AA6016 aluminum alloy; at room temperature, when the drawing speed is 3 mm•min^{-1} and the blank holder force is 1.2 N•mm^{-2}, a better drawing performance can be obtained, and the limit drawing ratio is

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1.7, which provides a theoretical basis for the application of AA6016 aluminum alloy in automobile body [5]. Minimizing of spring back by relaxation of stress through the targeted heating of materials in the radius area after the deep drawing process. In this study, experiments are conducted on a Dual Phase (DP) and TWining Induced Plasticity (TWIP) steels for the process feasibility study. This work analyses the influence of various heat treatment temperatures on the spring back reduction of deep drawn AHSS. The output of this research refers to new process approaches are regarded essential in order to optimize the forming process of AHSS in term of minimizing spring back., The local heat treatment in forming dies with the objective of relieving residual stress, changing the microstructure and reducing spring back can be successfully performed through induction heating. A feasibility study was made to show the potential of this idea on two UHS steel. The heat treatment process parameters i.e. the heating rate, annealing temperature and the cooling rate have a significant impact on the hardness values in case of DP steel, due to developing different martensite contents. And DP steel in comparison with TWIP steel, showed a better potential for the hybrid deep drawing process in order to reduce spring back [6]. The influence of temperature on the flow stress and the uniform strain of steel, brass, aluminum and AISI 304 and 316 type stainless steels by using uniaxial tensile tests. Sliding and stretching friction coefficients at several surface temperatures are measured for various sheets and lubricants using a bending under tension type strip drawing test. The validity of the results is verified by deep drawing experiments. The influence of temperature difference between the punch nose region and the flange on the drawing and fracture loads and on the limiting drawing ratio is determined [7]. Anisotropic properties of the sheet metals used for deep drawing have been studied for different metals, to specify the its effect on all parameters, The anisotropic properties of aluminium alloys and steel alloys have significant effect earing initiation and drawbility [8-11].
The microstructure and crystallographic texture evolution of continuous-cast, hot-rolled Al-Mn-Mg alloy sheet during cold rolling and subsequent annealing was investigated. All specimens cut from the as-received sheet were cold rolled and subsequently annealed, with some of these specimens receiving an intermediate heat treatment (IHT) prior to cold rolling. It was found that the degree of deformation and temperature of the annealing had a significant effect on the final grain size and texture of the sheet specimens, respectively. Furthermore, the IHT altered the development of the microstructure and texture of the final sheet specimens when compared to similarly produced specimens without it. Counterbalancing the deformation textures from rolling with a sharp Cube orientation from annealing may lead to reduced earing behavior of CC Al-Mn-Mg alloy sheet products during deep drawing applications. [12]. A Comparison of the formability of two different sheets by heat treatment and also varying the sheet thickness on angular die deep drawing process was done. For which both SS 304 and Brass each of 0.8 mm and 1 mm is considered in the present work. The experiments were performed by designing the deep drawing tools such as die, blank holder, and punch. Punch forces and thickness variations are evaluated for all the experimental test settings. The following conclusions were drawn from the work, Sheet thickness increased the drawing force required for deep drawing of the cups in angular deep drawing process, Heat treatment of the samples before forming reduced the wrinkles formation on the deep drawn cups, and Heat treatment of the samples also reduced the drawing force required to form the cups. [13]. The influence of heat treatment thereby hardness on flow ability of austenitic Stainless steel 304 foil of thickness 0.1mm was analyzed with Deep drawing process at calculated force. The wrinkle formation in the edges of the product due to less blank holding forces and the tearing of the metal due to low ductility is very difficult to maintain. The ductility mainly affects the limiting draw ratio of the cup shaped product. The main aim of this analysis is to increase limiting draw ratio of the material by improving its ductility with annealing process. The analysis is done to find the cause of the problem and thereby to get a possible best solution theoretically as well as experimentally. It can be concluded that the hardness of the stainless steel 304 was decreased after heat treatment process thereby increased its ductility and drawability that lead to increase the limiting draw ratio of the material which helped us to get the required depth of the product [14]. Numerical simulation of metal forming and deep drawing operations is progressively been established in the aeronautical sector while it is a common practice in the automotive sector, where this technique is used for the development of robust processes and precise forming tools decreasing the high set-up times. Post-forming springback is one of the major concerns when designing a new process and needed tools. Several authors are being currently working on this topic and the optimization of the prediction of the final springback using advanced numerical models, developing both advanced material and contact models. These studies include the Young modulus evolution with the plastic strain, the development of advanced material hardening models, improvement of current yield criteria and the use of advanced pressure, velocity and temperature dependent friction coefficients among others. In the present paper, the influence of intermediate heat treatments on the ductility-formability and the spring back of multi-stage deep drawing processes is studied for the Inconel 718 superalloy. For that, the Young modulus reduction and the formability increase are analyzed with and without heat treatments using cyclic tensile-relaxation and conventional

tensile tests. Results show he intermediate heat treatments increase the ductility of the material, making possible the forming of complex geometries. As it can be seen in the results the intermediate heat treatments recovers the initial characteristics of the Inconel 718 nickel base superalloy. The Young modulus reduction must be taken into account when forming processes are simulated, due to predict accurately the post forming phenomenon called spring back. [15]

2. Experimental Work

This section describes several test conditions, including crystalline structures and measurement of gran size, mechanical properties, as well as calculating values of work hardening index. The specimens have been subjected to recrystallization and stress relief heat treatments for investigating their effect on the metal drawability.

2.1. Characteristic and Preparation of Metal Specimens

The type of steel used for this study is SAE1006, this is proved with the chemical composition test that listed in table 1. The steel microstructure was also examined through the metallography test, where a small sample has been prepared with hot mounting, and 2%Nital etching media as shown in figure 1. As shown in figure 2 the microstructure consist of two phases the base phase is ferrite and there is grains of perlite phase. The grain size has been measured by using linear intercept method [wire], the grains was elongated in the rolling direction as it is significant in figure 2.

Table 1. SAE1006 composition.

element	C	Si	Mn	Ni	Cr	Mo	S	P	Fe
Wt.%	0.056	0.036	0.213	0.024	0.016	0.002	0.003	0.004	Rem.

Figure 1. The specimen for reveal microstructure.

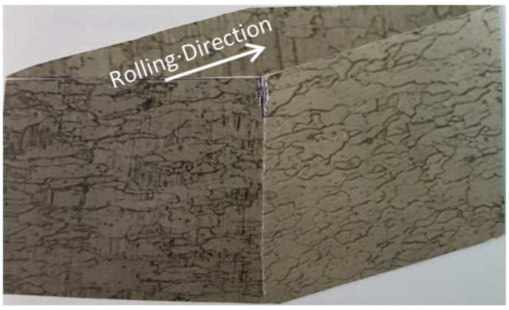

Figure 2. Microstructure of SAE1006 in rolling dimension as base.

2.2. Microhardness Tests

Microhardness test is one of the main mechanical property test. This test is used to measure the microhardness of the steel sheet used in deep drawing. The tests that were conducted on [micro hardness tester] (Adolph 1. Buehler INC.). The instrument used is MICROMET shown in figure 3. Two directions were measured, in the width and thickness directions using load of (300g). The surface sheet hardness, was for the specimens with and without heat treatment.

Figure 3. Microhardness tester.

By taking the average of the two diagonals lengths of the square indenture then converted to the Microhardness Vickers by using the tables. The results of the tests are shown in Table 2.

Table 2. The microhardness results for with and without heat treatment for width and thickness direction.

Microhardness without H.T.	Point1	Point2	Point3	Point4	Point5	Point6	Avg.
	90.4	86.9	90.4	84.8	90	86.9	88.23
Microhardness with recystall. Heat treatment	102	103	110	107	107	109	106.33
Microhardness with stress relief heat treatment	100	100	98.9	104	102	102	101.15

2.3. Work Hardening Index (n) Calculation for Steel Sheet

Work hardening index (n) is the formability induction, and for deep drawing drawability. Therefore it should be calculated from the tensile test data evaluated experimentally. Tensile test specimens were cut from the sheet metal, using ASTM E8 specification as shown in Figure 4 [5]. Three groups specimens were cut at (0°, 45°, 90°) with respect to rolling direction. These specimens are tensile tested, for obtaining stress- strain data. To calculate work hardening index (n) power law must be used:

$$\sigma = \kappa \varepsilon^n \quad (1)$$

Where σ = true stress in plastic range.

ε = true strain in plastic range.

κ = strengthen coefficient.

And n = work hardening index.

By taking the natural logarithm of the equation (1).

$$\log \sigma = \log \kappa + n \log \varepsilon \quad (2)$$

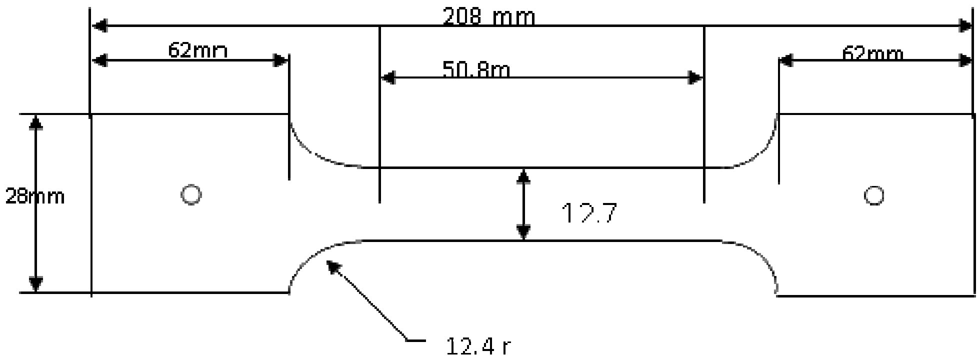

Figure 4. Specimen dimensions for tensile test.

2.4. Heat Treatments

2.4.1 Recrystallization Heat Treatment

It is a heat treatment used to regenerate a new crystal free of stresses with very low dislocations density. ThisoCcurs during heating at temperature about to 0.4-0.5 melting point temperature of a metal in kelvin scale. Recrystallization treatment used to nucleate new grains on the account of the original deformed grains. The aim of this heat treatment is to investigate its effect on the deep drawing drawability of the sheet metal. The experiment was conducted on tensile specimens. Using electrical furnace (type SALA BASIC LINDBERGE) the temperature was controlled to ±5°C. After the furnace reach 600°C, the specimens are entered in to the furnace for one hour and then air cooled. After this heat treatment the specimens were tested by the tensile test to obtain the engineering (stress-strain) curves for the three main rolling direction (0°, 45°, 90°). Converting the engineering stress – strain data to true stress strain data, and then compare the results for the as received steel sheet with the recrystallized annealed specimens for the anisotropic properties in the three sheet metal directions with respect to rolling direction.

2.4.2. Stress Relief Heat Treatment

This heat treatment used for reducing the strain hardening induce due to forming process, deep drawing process is one of sheet metal forming that exposed to high straining that effects steel sheet drawability. A new tensile test specimens are used for this experiment. This treatment has been done, as the furnace temperature became uniform at 500°C, the specimen are induce to furnace for one hour exposure time, and then air cooled. Then Data for tensile tests have been record to obtain the anisotropic properties in the three sheet metal directions with respect to sheet metal rolling.

2.5. Stiffness Test

Preliminary tests were conducted on various types of springs, in order to check the stiffness of the spring's (K) for each one.

2.6. Deep Drawing Test

The final aim is to establish the boundaries of the wrinkling and rupture zones when using Al-killed steel SAE 1006. Using 100-ton hydraulic press of single acting type, the blank holding force was achieved by using four spring system, and eight spring system, with stiffness 48 N/mm and 96 N/mm respectively. The blank diameter was (145mm) and (1mm) thick while the punch diameter (80mm) and die diameter was (82.5mm) giving a drawing ratio (R_d).

$$R_d = 145/80 = 1.8125 \quad (3)$$

The test commenced by using spring system, the blank holder being on the same level as the punch surface; this will give a force of (4×48=192 N). When we used the springs that had stiffness (48 N/mm) to show the wrinkling and working zones, wrinkling started after (24mm)-punch travel at (12mm) pre-compress. To delay wrinkling initiation, the blank holder level was raised above the punch by a further (1.5-mm), using spacer plate (washer) on top of the spring that was used. This would give a path force parallel to the first, wrinkling appeared at (27mm)-punch travel. Another experiment was performed using pre-compression of (14mm) and wrinkling was delayed to the depth of (43.5mm).

Total of (4) tests were made with different pre- compressions. As for the spring that had stiffness (96 N/mm) the initial force was (8×96=768 N) and without the use of spacing showed the rupture zone. Rupture started after (27.5mm)-punch travel. To accelerate rupture initiation, the blank holder level was raised above the punch by a further (3mm), using spacer plate (washer) on top of spring used. This gave a path force parallel to the first and rupture appeared at (23.5mm) punch travel. Another experiment was done using pre-compression of (16mm) and the rupture was accelerated to the depth (17mm). Total of (4) tests were made with different pre-compressions the curve of the wrinkling and rupture zones. To investigate the quality of the product soundness, the variation of thickness along the qualified product was measured. Using a micrometer, six readings was recorded from the edge of the cup to the bottom, the results were taken as a percentage to the original thickness,

3. Results and Discussions

After tensile test was preformed, a comparison between the engineering stress- strains curves of the three directions are represented in figure 5 this figure in the same line with standards which approve that the properties in rolling direction have the highest values.

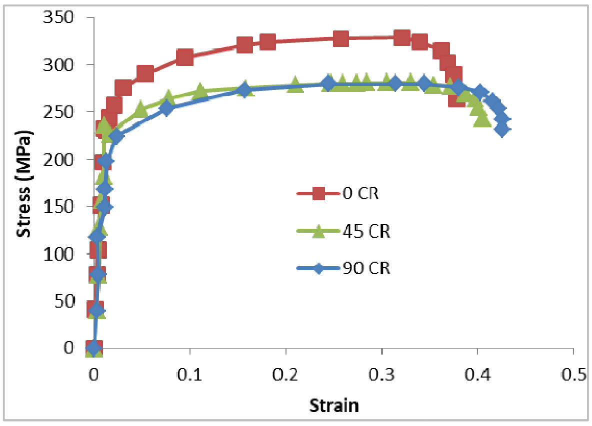

Figure 5. Comparison between the three direction to rolling stresses and strains values.

Another compression are represented graphically between the cold rolled and recrystallization and stress relief for the three direction of rolling in figure 6, 7, and 8 respectively. The results obtained are converted to the true stress-strain values and then converted to log stress-log strain to obtain the (n) value from the slope, n values are shown in table 3 for each direction and in the two cases with and without heat treatment.

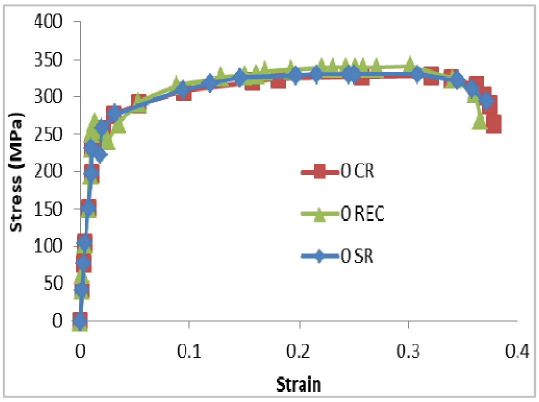

Figure 6. Recrystallization and stress relief effect on stress strain values in rolling direction.

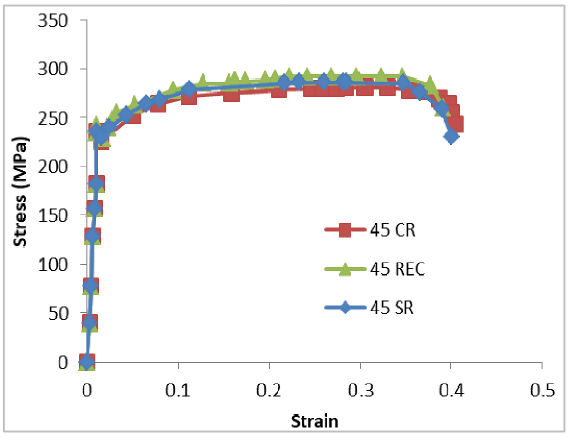

Figure 7. Recrystallization and stress relief effect on stress strain values across rolling direction.

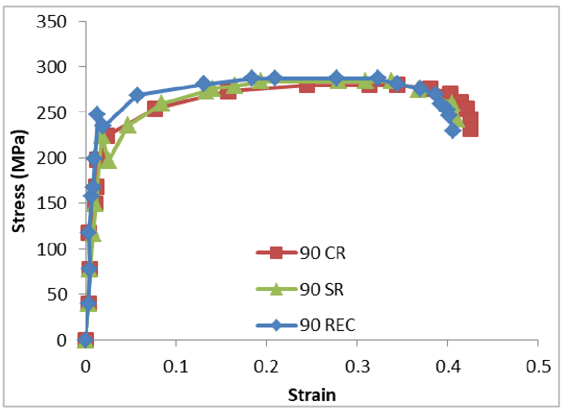

Figure 8. Recrystallization and stress relief effect on stress strain values perpendicular to rolling direction.

In the three above curves it is clear that the metal loss some drawability As a result of the rise in stresses relative to the strains, which are in line with the decline in values of exponent of strain hardening in the three direction to rolling as shown in table 3, It is worth mentioning that the recrystallization heat treatment has the greater effect on the mechanical properties of the metal than the stress relief heat treatment. Therefore these heat treatments had a bad effect on the deep drawing process by increasing metal strength and reducing the drawability of the metal.

Table 3. the values of strain hardening index in three directions with respect to rolling directions.

Angle to rolling direction	0°	45°	90°	Avg.
(n) values for cold rolled specimens	0.35	0.33	0.32	0.33
(n) values for recrystallized specimens	0.24	0.22	0.21	0.22
(n) values for stress relived specimens	0.28	0.26	0.23	0.25

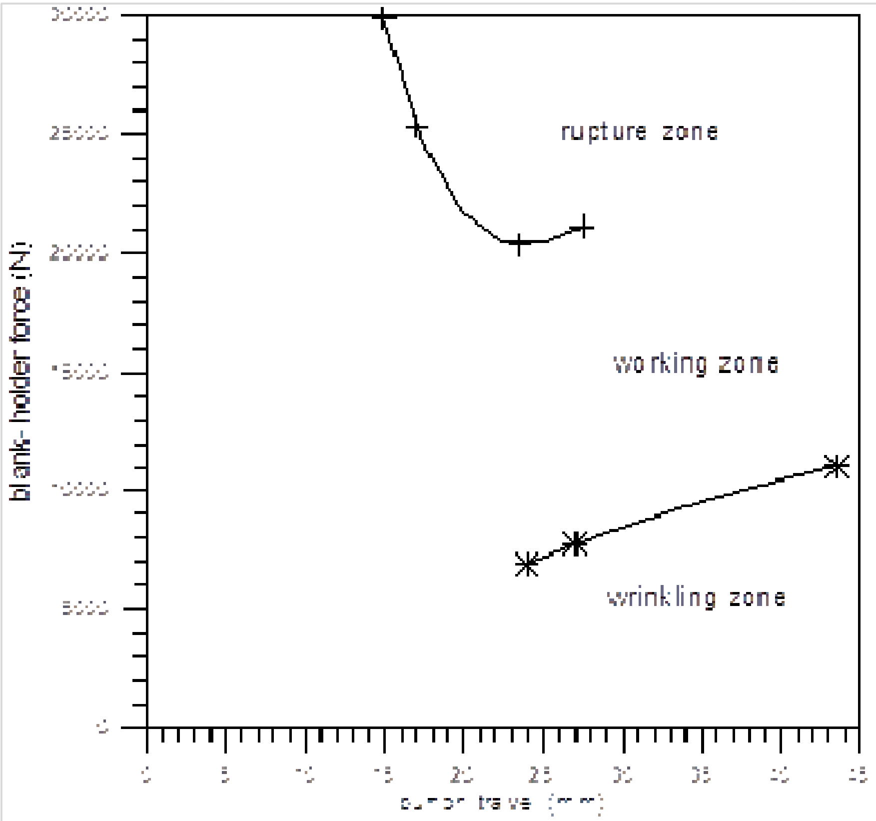

Figure 9. Shows the effects of springs stand and there effects on creation ruptures and wrinkling.

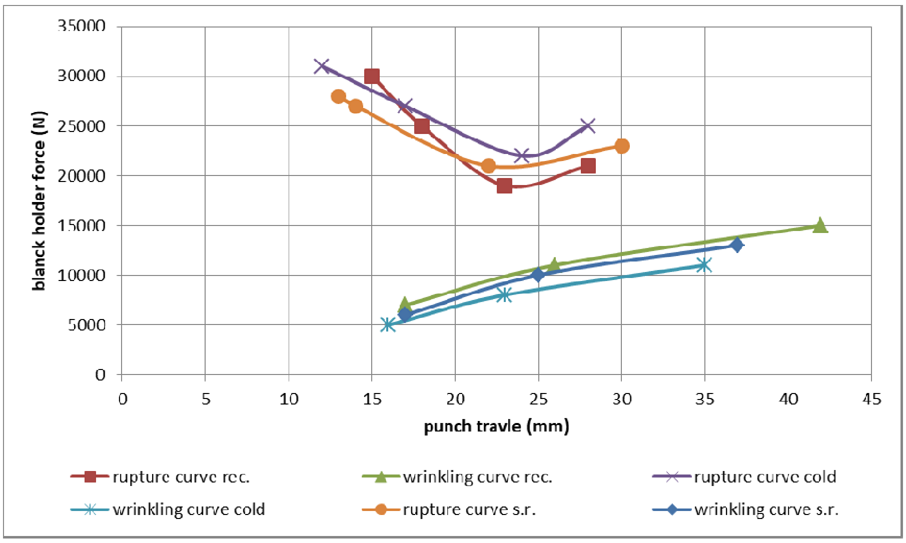

Figure 10. Comparison between rupture and wrinkling zones for heat treated and non- heat treated specimens.

In the same manner blanks heat treated in furnace at 600°C and 500°C for recrystallization and stress relief respectively, and the rupture - wrinkling curves were drawn to compare these results with that obtains for non heat treated specimens, this comparison was shown in figure 10 which enhanced the results of tensile test cause in the recrystallization and stress relief heat treatments the working zone become more narrow than the cold rolled curves which mean difficulty of deep drawing process.

The ruptures and wrinkling defects that developed during deep drawing the for the blank holder force and measuring the punch travel distance, at this study conditions the ruptures curves accumulate at high blank hold force [16, 17], and the as received blanks are more sense to rupture than other heat treated sample because of its less strength, while at the wrinkling zone the opposite sense have been records, the blanks are more affected with the traveling punch distance and the recrystallized blanks show more ability to wrinkling than the stress relief and cold rolled blanks because of its higher strength and less ductility. And that is true because the work hardening index (n) in table 3 for recrystallized annealed specimens are lesser than others, which means lower formability, more wrinkling ability [18].

4. Conclusions

Concerning the experimental work conducted in the present work, the following conclusions can be drawn:

I. To produce a sound product it is necessary to establish the blank holder- punch travel diagram for each material, and die to fix the wrinkling, rupture, and working zones. By this method it is possible to succeed the safe zone as a holding force, when one of any factors is changed because of any reason.

II. The recrystallization heat treatment, which is used in present work, has a bad effect on the drawability on the steel SAE 1006.

III. Stress relieving treatment for the used steel SAE1006 has a bad effect on the drawability of the metal too.

IV. The deep drawing blank show an anisotropic properties with respect to rolling directions, and obey power law for calculation of work hardening index.

5. Recommendations

I. For further study it is recommended to used strain gages measure the strains at each travel distance and blank holder force.

II. And also it is recommended to study effects of heat treated blanks with different punch diameters sizes.

III. It is recommended to study effects of heat treated blanks for rectangular shape beep drawing.

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