COMPARATIVE STUDY OF FORMABILITY AND MECHANICAL PROPERTIES OF AISI316 AND AISI430 STAINLESS STEEL

João Pedro Santiago Carneiro(*) , José Rubens Gonçalves Carneiro, Gilmar Cordeiro da Silva, Pedro Paiva Brito
Department of Mechanical Engineering, Pontifícia Universidade Católica M.G., Belo Horizonte, Brazil
(*)Email: jsantiagocarneiro@gmail.com

ABSTRACT
Stainless steel sheets are used for kitchen, building, transportation, because of their high corrosion-resistivity and their appearance.
This study is focused on comparing the mechanical properties and formability of the AISI316L and AISI430 Stainless Steel.
Tensile test to determine anisotropy and work hardening exponent, Swift test to find out the Limit Drawing Ratio and determination of Forming Limit Diagram of both steels were carried out in order to compare formability of those two stainless steels.

Keywords: AISI316, AISI430, forming, forming limit diagram, limit drawing ratio.

INTRODUCTION
In metal forming technologies, the stamping process for sheet metal is one of the significant manufacturing processes. The design of stamping processes has been performed by either a trial-and-error approach or finite element analysis. (TAKUDA et al, 2003).
Ferritic stainless steel AISI 430 has a low thermal expansion rate and excellent mechanical properties and formability. AISI430 is cheaper than 300 series of austenitic steels, but is more susceptible to corrosion too due to its free of nickel (WANG et al, 2013). Therefore, the demand of AISI430 is very large and it is usually used for manufacturing heat resistant instruments, burners, household appliances, tableware, kitchen sink and external decoration materials

Stamping is a manufacturing process which forms a metal plate. It is characterized by forming low thick sheets by great contact areas. There are three basic manners of stamping are bending, mounting and stretching.
Bending process is one of the most common operations of sheet forming and could be done with or without overlapping stresses.
The stretching could be described as a process in which sheet is pushed down inside a die by a metal or rubber punch or directly by a high pressure oil, while a brake or a blank holder are responsible for holding the sheet. In Biaxial stretching process, positives strains at directions of plate plan and decreasing of sheet’s thickness happens (DINIZ, 2000), during the process, circular strain is zero in the piece ends and as closer to the center of the sheet, higher the circular strain value.
Mouting is a process in which a plate is pushed into a die by a punch a blank holder allows sheet’s sliding in circumferential direction (DINIZ, 2000). However, the majority of stamping processes are combinations between stretching and mounting.

Measurements of mechanical properties by tensile test is not usually sufficient due to complexity of stamping operations. Specimens, usually called blanks, could have circular, elliptical and rectangular forms. Punches also have different forms and dimensions.

In general, the pressure on the blank holder is minimum in order to avoid wrinkle formation and allow flange’s material to flow inside die. Actually, a forming until the fracture is not possible by pure stamping because of the material strains just until a certain point by stamping.

Execution of various tests is necessary in order to evaluate the formability of a metal sheet. Examples of these tests are Swift test and test to determine a forming limit curve of a specific material.

In Swift test, a series of tests are carried out in which the dimensions of the specimen gradually increases until a situation that the material could not be drawn more, in other words, the material fractures before being completed mounted. The measures value is called LDR (limit Drawing Ratio).

Formability of the material increases by increasing the temperature because of decrease in the mean flow stresses. The formability is also affected by the material properties and the microstructure that changes by the temperature at which the material is deformed. (Lade et al, 2007).

Formability of sheet metal is assessed by the strain distribution during deformation and it predicts in terms of forming limit diagram (FLD), which presents the different deformation paths of the material. The FLD shows the correlation between the first principal strain ($\varepsilon_1$), which is major in the plane of the sheet metal, and second principal strain ($\varepsilon_2$), which is minor in the plane of the sheet metal. It provides a graphical description of sheet metal failure by mapping a forming limit curve (FLC), which indicates the maximum strain in sheet metal without fracture. It represents a limiting curve in FLD, up to which the material can be formed before fracture. (HUSSAINI, et al, 2015)

Materials which have the ability to distribute strains more uniformly are below the FLC and expected to have higher formability. With the help of FLD, it is possible to evaluate different strain conditions in the same diagram and determine the fracture limit for the particular strain combinations.

**EXPERIMENTAL PROCEDURES**

Tensile testing was carried out at FIAT automobiles in the steels studied in an Instron machine, strain rate was 0.1 s$^{-1}$. Tests were made in 18 samples of these 2 steels in angles 0, 45, 90$^o$ to rolling direction, three samples in each direction.

The specimens were made from a sheet of 2.0 mm thick for AISI 430 and 1.8 for AISI 316L. The design of the specimens was according to the standard ASTM E8.

The results from tensile test came as tensile load in a function of displacement, therefore it was necessary to transform load into true stress and displacement into true strain, and graphic true stress vs true strain was plotted, then ultimate stress and yield stress were found out.
Using mathematical tools, parameters work hardening coefficient \((n)\), normal anisotropy and plane anisotropy were found out.

50x50x2 mm 316L and 430 steels strips were cut and chemical analysis was done in FIAT Automobiles laboratory.

The samples were embedded in a self-curing acrylic resin and grinded manually on a180, 220, 400, 600 and 1200 mesh of grain size. After mechanical sanding, Polishing operations were carried out in a abrasive material felts. Diamond paste used in the polishing operation has 9 and 3 \(\mu\)m.

Chemical etching in both stainless steels were done by oxalic acid 10% v/v, a optical microscope coupled with an image analyser, both brand Zeiss, has been used in order to view all microconstituents.

Two samples 250 mm diameter of AISI 316 L and other two of AISI 430 steels were stamped by a 120 mm diameter punch The machine with the die, punch, blank holder responsible for this process is illustrated in figure 1. The machine used in this test was the same for every forming test carried out in this study, changing die, punch and blank holder.

![Fig. 1 - Machine used to forming tests and die to stamp 250 mm diameter samples of steels studied](image)

316 and 430 steel with 1 mm in thickness were made the Swift test in order to determine LDR(Limit Drawing Ratio). A punch with 50mm diameter forms some blanks, pressure in the blank holder was 10 kgf/cm\(^2\) and the speed was not controlled, however, it was maintained low.

The diameter of them initiate in 80 mm and varies, grown 5 to 5 milimeters until some crack appeared when blank was stamped. There was not any lubricant utilized.

In order to obtain forming limit curve, the samples were produced cutting AISI316L and AISI316L. 5 plates of each material were obtained on dimensions of 180x180, 180x 150, 180x 120, 180x 90 e 180x 60 milimeter.
They were painted using Prussian Blue, and then, scratched in order to form many 5x5 mm squares.

Sheets were put in die, and a blank holder in a same part (illustrated in figure 2), and being formed.

Fig. 2 - Die used to obtain the FLD

Squares, after the forming process happened, had its dimensions measured close to fractured region and in the fractured region, excluding fracture size. After the strains were calculated. Then graphics were plotted using information obtained before.

RESULTS

The chemical composition of AISI316L and AISI430 steels was determined using a 50x50x2 mm specimen (Table 1).

<table>
<thead>
<tr>
<th>Steel</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Ti</th>
<th>Al</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>430</td>
<td>0,029</td>
<td>0,44</td>
<td>0,35</td>
<td>0,036</td>
<td>0,0024</td>
<td>15,54</td>
<td>0,18</td>
<td>0,006</td>
<td>0,002</td>
<td>0,010</td>
<td>0,055</td>
</tr>
<tr>
<td>316L</td>
<td>0,009</td>
<td>1,50</td>
<td>0,408</td>
<td>0,035</td>
<td>0,003</td>
<td>15,70</td>
<td>9,80</td>
<td>1,960</td>
<td>0,005</td>
<td>-</td>
<td>0,037</td>
</tr>
</tbody>
</table>
In table 1, it could be observed that nickel percentage in the AISI430 is lower than in AISI316L, also has less other elements. Microstructures of AISI430 and AISI316L steel are shown in figure 03 (a) and (b)

![Microstructure of AISI430 steel](image1) ![Microstructure of AISI316L steel](image2)

Fig. 3 - Microstructure of AISI430 and 316L steel after chemical etching with oxalic acid 10% v/v

In table 2, it is showed the mechanical properties, yield stress, ultimate stress, work hardening exponent, normal and planar anisotropy of the steels studied.

<table>
<thead>
<tr>
<th>Steel</th>
<th>Yield stress (MPa)</th>
<th>Ultimate stress (MPa)</th>
<th>Hardening exponent (n)</th>
<th>Normal Anisotropy</th>
<th>Planar Anisotropy</th>
</tr>
</thead>
<tbody>
<tr>
<td>316L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>303,74±7,59</td>
<td>621,91±1,52</td>
<td>0,32±0,003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45°</td>
<td>301,66±3,64</td>
<td>605,96±3,20</td>
<td>0,32±0,006</td>
<td>0,85±0,35</td>
<td>0,04±0,19</td>
</tr>
<tr>
<td>90°</td>
<td>311,30±5,80</td>
<td>623,94±3,19</td>
<td>0,32±0,007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>430</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>306,81±9,62</td>
<td>473,22±5,25</td>
<td>0,19±0,003</td>
<td>0,96±0,28</td>
<td>0,54±0,07</td>
</tr>
<tr>
<td>45°</td>
<td>345,81±9,29</td>
<td>504,35±0,96</td>
<td>0,17±0,010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90°</td>
<td>334,25±1,17</td>
<td>501,13±0,22</td>
<td>0,18±0,002</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is showed in table 2 that the yield stress determined by tensile test was almost the same considering the 2 stainless steels in this study, however, 316L’s ultimate stress is 23% higher than the 430’s one. The work hardening exponent (n) of the AISI316L is the highest considering the steels studied, which would evince the best formability.

The 250 mm diameter AISI 316L and 430 blanks were deep drawn, and then, it could be observed that only 430 Ferritic stainless steel fractured as indicated figure 4.
Fig. 4 - Stamped blanks, which has been already bored. (a) AISI316L (b) AISI430.

The testing results of limit drawing ratio are shown in table 3.
Table 3 - Outcome of Swift test made to determine Limit Drawing Ratio (LDR) of AISI 316L and 430 steels

<table>
<thead>
<tr>
<th>Steel</th>
<th>Blank diameter, in which blank was stamped successfully (mm)</th>
<th>Diameter of fractured blank (mm)</th>
<th>LDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 430</td>
<td>80</td>
<td>85</td>
<td>1.6</td>
</tr>
<tr>
<td>AISI 316L</td>
<td>90</td>
<td>95</td>
<td>1.8</td>
</tr>
</tbody>
</table>

The forming limit diagram of both steels studied is determinate on the figure 5 (a) and (b)

![FLD for AISI 316L](image)

(a)

![FLD for AISI 430](image)

(b)

Fig. 5 - FLD for two different sheets (a) AISI316L (b) AISI430.

**CONCLUSION**

There is clear evidence that the formability of AISI316L is higher than AISI 430. The study shows that there are not substantial differences on elastic properties, but the plastic properties, hard working exponent and ultimate stress, are different between these steels. 316L steel’s LDR value is greater than 430’s one and the forming limit of AISI316L also is greater.
ACKNOWLEDGMENTS
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