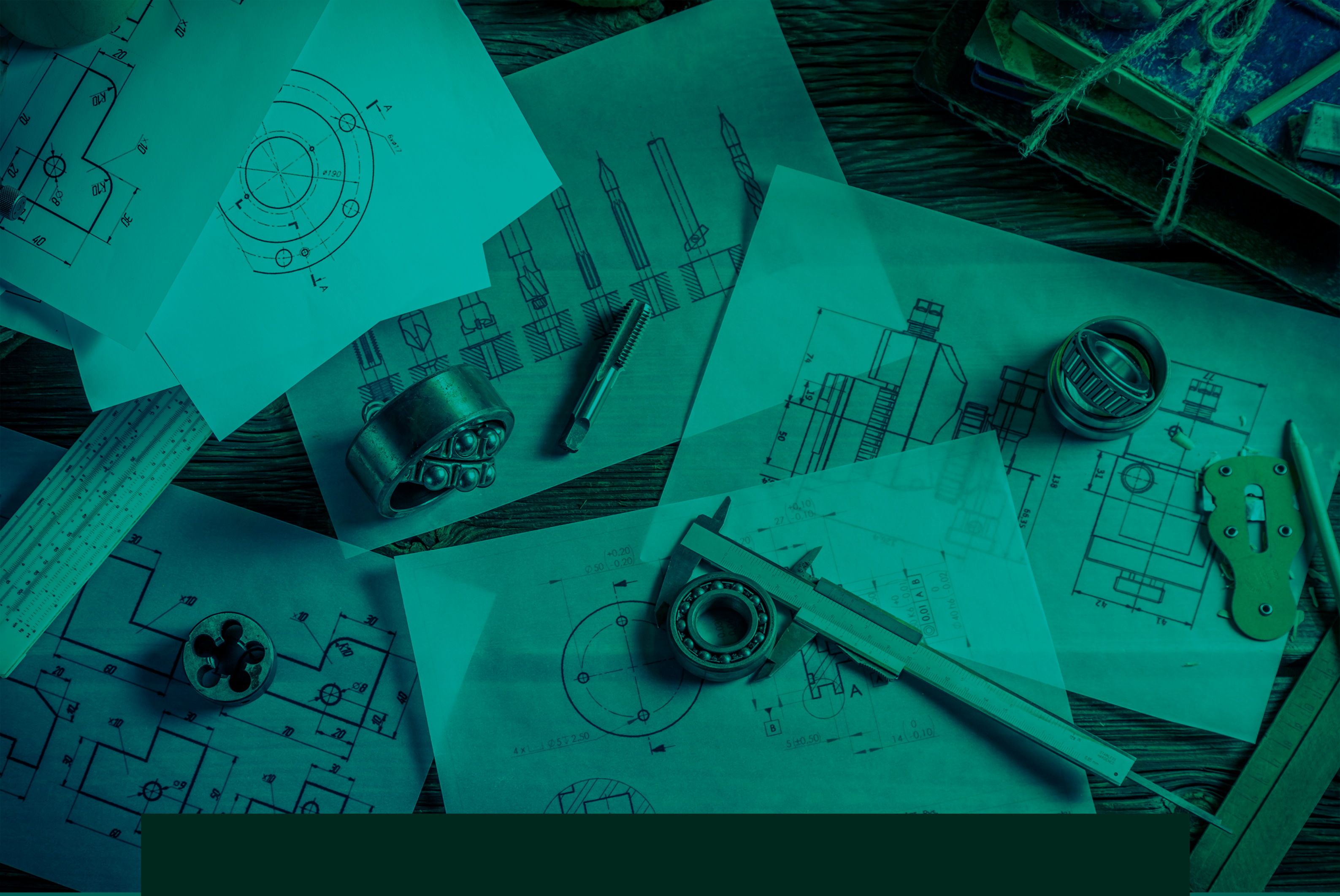

Henrique Ajuz Holzmann
(Organizador)

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APRESENTAÇÃO

A Engenharia Mecânica pode ser definida como o ramo da engenharia que aplica os princípios de física e ciência dos materiais para a concepção, análise, fabricação e manutenção de sistemas mecânicos. O aumento no interesse por essa área se dá principalmente pela escassez de matérias primas, a necessidade de novos materiais que possuam melhores características físicas e químicas e a necessidade de reaproveitamento dos resíduos em geral.

Nos dias atuais a busca pela redução de custos, aliado a qualidade final dos produtos é um marco na sobrevivência das empresas, reduzindo o tempo de execução e a utilização de materiais.

Neste livro são apresentados trabalho teóricos e práticos, relacionados a área de mecânica e materiais, dando um panorama dos assuntos em pesquisa atualmente. A caracterização dos materiais é de extrema importância, visto que afeta diretamente aos projetos e sua execução dentro de premissas técnicas e econômicas.

De abordagem objetiva, a obra se mostra de grande relevância para graduandos, alunos de pós-graduação, docentes e profissionais, apresentando temáticas e metodologias diversificadas, em situações reais.

Sendo hoje que utilizar dos conhecimentos científicos de uma maneira eficaz e eficiente é um dos desafios dos novos engenheiros

Aos autores, agradeço pela confiança e espirito de parceria.

Boa leitura

Henrique Ajuz Holzmann

SUMÁRIO

CAPÍTULO 3

STUDY OF DIFFERENT LUBRI-COOLANT CONDITIONS FOR INCREMENTAL SHEET FORMING OF THIN ZINC SHEETS

Data de aceite: 12/02/2020

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ABSTRACT: This study aims to evaluate the behavior of zinc sheets using single point incremental sheet forming process under four different lubricants. This stamping technique has gained prominence because it allows forming in CNC machining centers, without the need for specialized tooling, allowing the process of sheet forming at a relatively low cost. Part geometry was generated in a CAD/CAM software and plates were fixed in the CNC machine through a clamping device. Parameters were set according to works of previous authors in stamping of zinc and stainless steel parts. Roughness tests were conducted to evaluate surface quality, and material mechanical properties were assessed through tensile tests. Results indicated that the zinc covered steel used possess good formability. Besides a slightly better surface quality was observed for lubricant containing graphite.

KEYWORDS: Zinc sheets, Incremental Sheet Forming, lubrication.

1 I INTRODUCTION

Mechanical forming process are those that aim to change the shape of a metallic body to another defined form without material removal, through plastic deformation. These include folding, lamination, forging, drawing and stamping, which are traditional strategies and differ as to the type of stresses applied and the working temperature.

Modelling of sheet metal or stamping is of special interest in the automobile, naval and aerospace industry, medical area and even for household items. However, most of the cited processes are intended for the production of large and medium lots, through use of extensive tooling, equipment and resources, such as hot and cold press, hard steel dies and heat treatment oven. These work well for production lines, yielding lower cost per piece. However, when a product is being developed and a prototype is necessary, or when the quantity to be produced is in small, conventional stamping would be appropriate (TIBURI, 2007). Incremental Stamping or Incremental Sheet Forming (ISF) is an alternative process, which allows obtaining complex geometries with a CNC machine and simple tools, as used by Cao (2015) in studies of incremental forming. Nilsson (2002), whose results serve as a guide, has applied this process to zinc stamping jobs in profitable condition. There is vast literature on the process and it can be applied under various conditions, not only in metals but also in polymers. It also has a proven economic advantage under certain conditions, such as complex parts, when compared to conventional stamping. Mass and volume are kept constant, but material form and mechanical properties change according to process parameters such as tool rotation and feed, lubrication and tool path.

This work presents a study of this technique applied in pure zinc sheets of 0.5 mm thickness under different lubrication conditions. Final depth of stamped parts, presence of cracks due to processing and surface finish were assessed. The material initial mechanical properties and metallography were assessed and help to explain the influence of material characteristics in process results. Anisotropy coefficients were measured, and the influence of lubricating fluid in the process was discussed.

2 I MATERIALS AND METHODS

2.1 Materials used

The formability essays were performed on zinc sheets cut from a laminated blank to square shape of 240 mm wide and 0.5 mm thick. The tool used is 12 mm in diameter and a semispherical cap was turned from an AISI52100 steel rod. Before every test, its surface condition was verified by unaided eye and grinded in 300 mesh sandpaper when wear of the tip was apparent. All essays were performed on a CNC ROMI Discovery 760 machining center with 9 kW power capacity in the spindle.

Four different lubricants were used as follows. Semi-synthetic SAE 10W30 oil, which has viscosity of 4.1 mm^2/s in room temperature and 9.3 to 12.5 mm^2/s at 100ºC, besides 0.882 g/cm^3 density. Mono-viscous oil for SAE 90 gearbox with viscosity between 13.5 and 24 mm^2/s and 0.89 g/cm^3 density. Mix of SAE 90 oil with graphite as solid lubricant, which was added at the proportion of 10 g of graphite to 90 g of SAE 90 oil. At last, a test with a minimum quantity of lubricant (MQL) with a flow rate of 50 mL per hour was performed. For the metallographic analysis, samples were sequentially grinded on sandpapers of mesh 120, 250 and 300, polished and then etched in aqua regia. Scanning electron microscope (SEM) from HITACHI model TM 3000 was used to inspect the surface from one of the samples. Finally, tensile tests were performed using three specimens taken from undeformed sheets, within lamination direction of 0º, 45º and 90°. The machine for the tensile essay was a SHIMADZU AG-X with load cell capacity of 300 kN.

2.2 Experimental Procedure

Initially, geometry of the final part was generated in CAD software, being a cone trunk with a slope of 45º. Tool path was produced through CAD/CAM system. Inside the CNC, a clamping device having several tightening screws was used to fasten the sheet. Tool was placed in the tool holder replacing the traditional milling tools. All the four tests were performed with tool feed rate of 250 mm/min and rotation of 1000 rpm.

After the incremental sheet forming trials, the parts were cut with an abrasive disc and then embedded in bakelite. They were subsequently subjected to manual grinding, changing direction (90°) in each subsequent sanding until the traces of the previous sanding disappear. Lastly, samples were polished with chromium oxide particles of 5μm. Metallographic analysis was performed in an optical microscope. Etching employed aqua regia for a period of 1 minute. Four samples corresponding to each test and two referring to the non-deformed sheet were analyzed. A chemical composition analysis was performed using Energy Dispersive X-ray Spectroscopy (EDS) from SEM.

The three tensile tests were carried by fixing the test specimens in the machine and placing a strain gauge on them, measuring the deformation during application of the quasi-static load. Obtained values were registered in a spreadsheet and plotted in stress x strain curves. Fig. 1 represents the samples cut by portable electric scissors, in accordance to ASTM E8 – 16a.

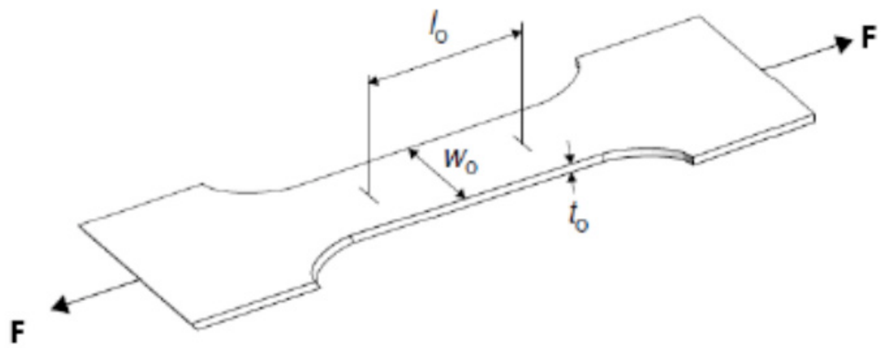

Figure 1. Scheme of the test specimens used in the tensile test

2.3 Governing equations

The following equations were also previously studied in previous related works, as done by Al (2017). From the data collected after the tensile test, it is possible to obtain the conventional stress σ, which is the ratio between the applied force (F) and the area of the initial transversal section (A_0), as shown in Eq. (1).

$$\sigma = \frac{F}{w_0\ x\ t_0} = \frac{F}{A_0} \tag{1}$$

The relative tension (ε) is the relationship between the variation of the length by the initial length (l_0) and the instantaneous length of the specimen at the time of the test, as shown in Eq. (2).

$$\varepsilon = \frac{l - l_0}{l_0} \tag{2}$$

In fabrication by incremental sheet forming it's desirable for the material to have a high value of medium anisotropy, meaning a greater resistance to the decrease of its thickness during the process. This coefficient is obtained by the tensile essays on specimens at 0°, 45° and 90° of the rolling direction according to ASTM E517-00, and is given as the ratio between the true width deformation (φ_2) and the deformation of the thickness (φ_3). By definition, the anisotropy rate or coefficient of Lankford (r) is the ratio between the true width deformation and the true deformation of the thickness of a tensile test specimen, and can be calculated by Eq. (3).

$$r = \frac{\varphi_2}{\varphi_3} = \frac{ln\frac{t_0}{w_0}}{ln\frac{w_0.l_0}{t_0.l}} \tag{3}$$

t_0 is the initial thickness of the specimen submitted to the tensile essay, w_0 is the initial width of the specimen and l_0 is the initial length. l is the instantaneous length of the specimen along the test. An ideal material to the ISF would be that in which the coefficient of anisotropy tended to infinity, that is, with deformation only in width and length. Anisotropy can be normal or planar. The normal anisotropy is indicative of the capacity of the metallic sheet to resist to the decrease of the thickness when being pulled and can be calculated by Eq. (4). When it presents value 1, there is equality between the resistance to deformation at the length and at the thickness. When greater than 1, the sheet offers greater resistance to the plastic deformation in its thickness direction. Planar anisotropy is indicative of the variation of the anisotropy coefficient between longitudinal and transverse directions of lamination and can be calculated by Eq. (5).

$$r_m = \frac{1}{4}.(r_{0º} + 2.r_{45º} + r_{90º}) \tag{4}$$

$$\Delta r = \frac{r_{0º} + r_{90º}}{2} - r_{45º} \tag{5}$$

3 I RESULT AND DISCUSSION

3.1 Incremental sheet forming

Figure 2 shows the side and top views of the generated geometries after the incremental sheet forming trials. The upper and lower marking refers to the beginning site, outermost region, and the region at the end of the process, respectively. The shape of the cone at the end of the process was always the same predicted by the CAD/CAM system, indicating good stampability.

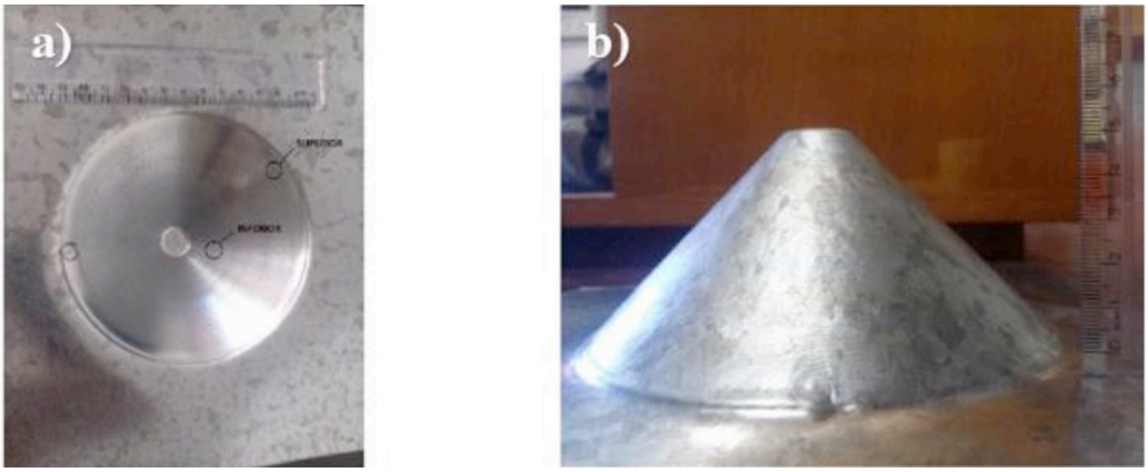

Figure 2. a) Top view of final part. b) Side view.

3.2 Coefficient of anisotropy

The two parameters obtained from tensile tests on zinc sheets were stress (N / mm²) and displacement (mm). Together with initial measurements, relative deformation (ε) can be calculated by Eq. (2) and thus obtaining the true stress curves out from the engineering stress x strain curve, which does not account for reduction of transverse section. Data for samples obtained in lamination direction is presented in Fig. (3).

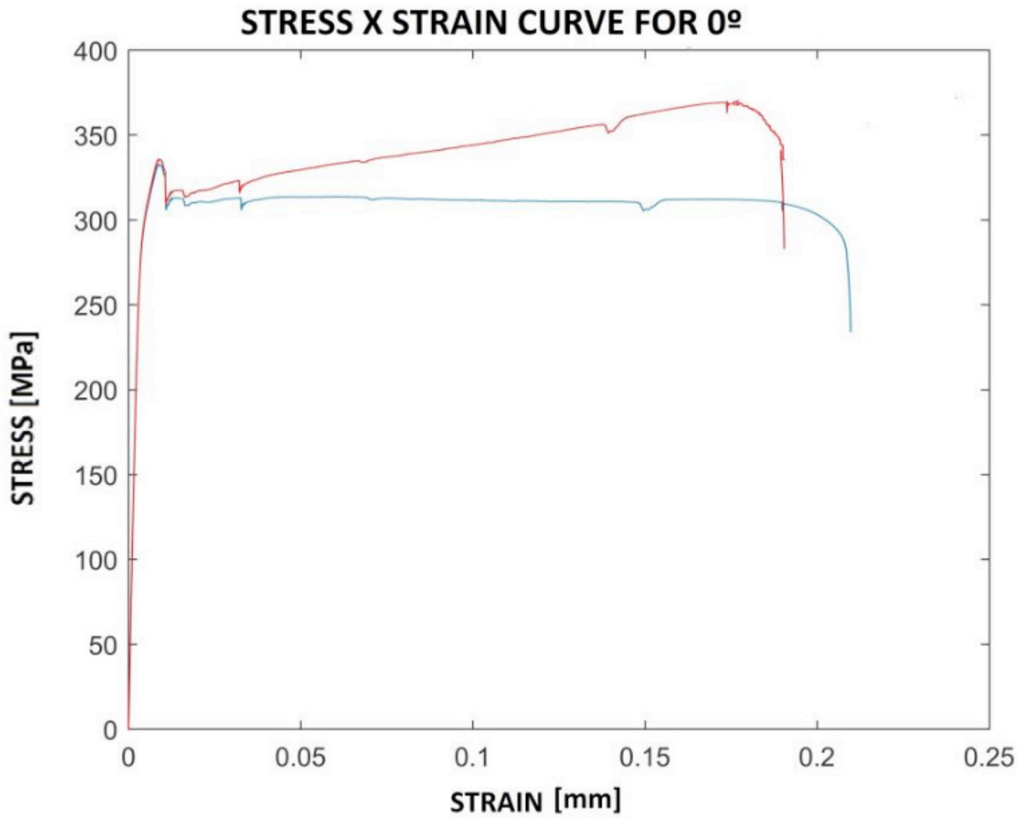

Figure 3. Stress x Strain curve for 0º (Red: true stress curve, Blue: engineering curve).

It is possible to observe a well-defined elastoplastic transition which occurs abruptly, marked by an upper and lower flow limit. The plastic deformation starts at the upper yield stress and, with a decrease in stress, the deformation oscillates slightly around a constant value (lower yield limit). After the transition, the deformation remains at a virtually constant tension value, with a tendency to a straight line. For the test at 45°, a very clear transition is not noticeable as in the first case. However, it is possible to observe the characteristic fluctuation of the lower flow limit, present in the deformation by up to approximately 5%, followed by an increase in tension with the deformation, as shown in Fig. 4.

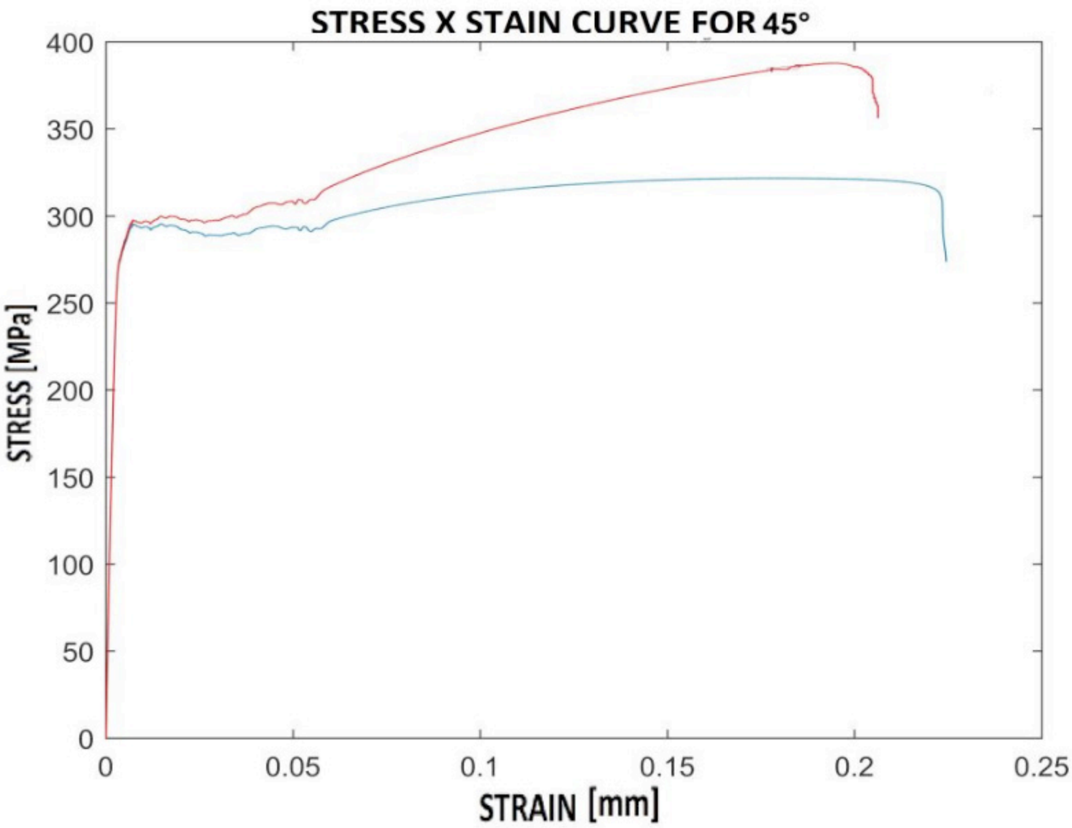

Figure 4. Stress x Strain curve for 45º (Red: true stress curve, Blue: engineering curve).

With a behavior similar to the previous one, in the test with sample orientation perpendicular to lamination direction, shown in Fig. 5, it is also possible to notice the characteristic fluctuation of the lower flow limit until a deformation of 5%, followed by an increase of the tension as the deformation increases.

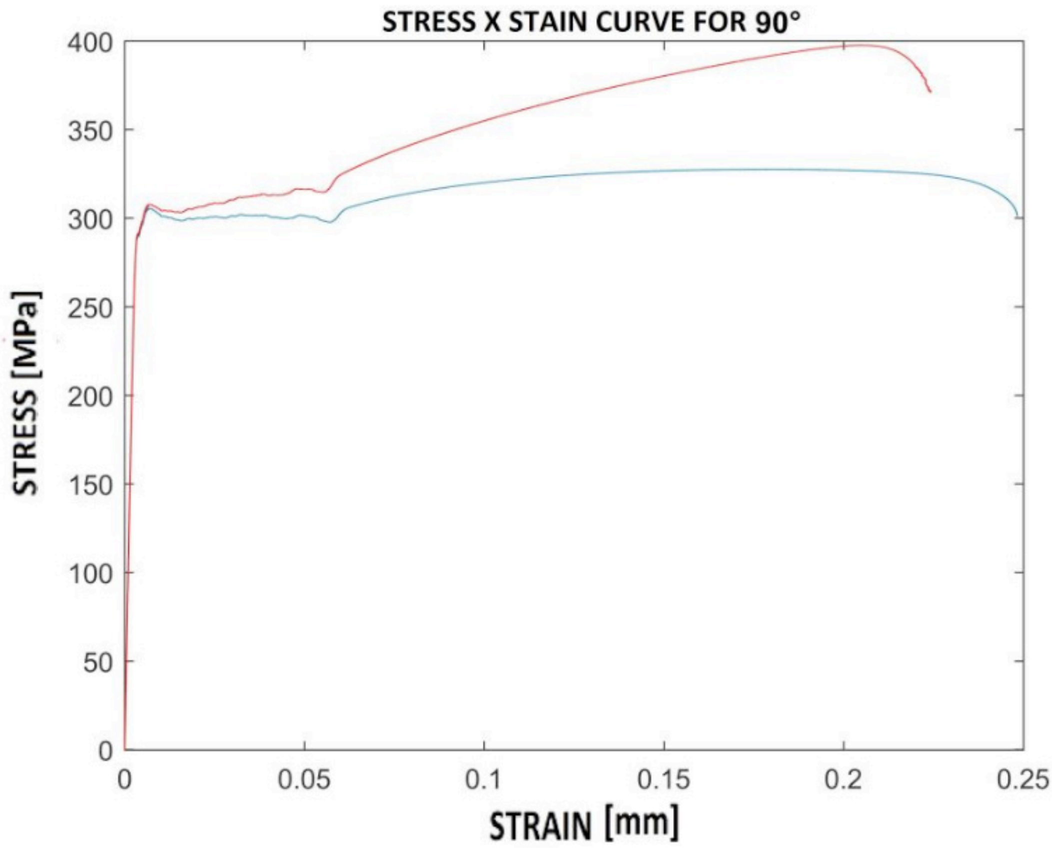

Figure 5. Stress x Strain curve for 90º (Red: true stress, Blue: Engineering)

To evaluate the anisotropy degree, specimens were measured after the tensile tests and then the deformations at length (φ_1), width (φ_2) and thickness (φ_3) were calculated by comparing to the values before the test using Eq. (2) and Eq. (3). Table 1 shows the final dimensions and the deformations of the specimens and the values of Lankford coefficient for each direction.

	LENGTH	WIDTH	THICKNESS	φ_1	φ_2	φ_3	r
0º	157.00	9.83	0.43	0.11	-0.22	-0.15	1.46
45°	160.20	10.17	0.48	0.14	-0.19	-0.04	4.75
90º	163.50	10.08	0.41	0.16	-0.20	-0.20	1.00

Table 1. Final dimensions and deformations of test specimens

Through Eq. (4) and Eq. (5), it is possible to calculate the values of the normal anisotropy (r_m) and planar anisotropy (Δr), yielding 2.99 e -3.5, respectively. Once the value of normal anisotropy is greater than 1, we can conclude that the sheet presents higher resistance to plastic deformation at the thickness, being deformed mainly at length and the width, according to studies of Melconian (2014). Regarding the planar anisotropy (Δr), the value found indicates that there is a great variation of normal anisotropy between the longitudinal and transverse directions.

3.3 Scanning electron microscopy (sem) and energy dispersive spectroscopy (EDS)

Fig. 6 shows an image of the sheet seen from above in SEM equipment, whereas the respective spectrum of EDS was generated for the indicated point. Table 2 shows the results of the EDS evaluation of the whole area seen in Fig. 6, indicating that the material has a zinc purity of about 97.5 %.

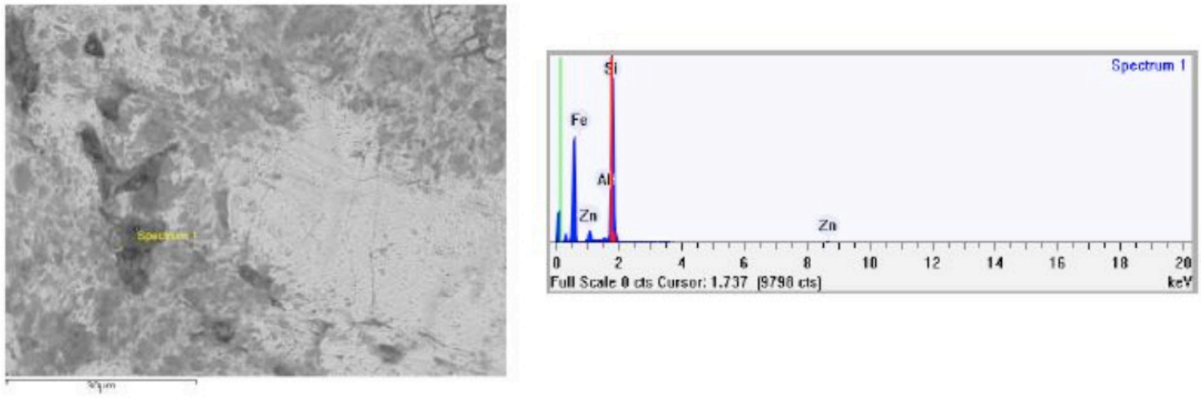

Figure 6. Left: SEM image of surface. Right: EDS spectrum for the indicated yellow point.

Element	% Weight
Zinc	97.772
Iron	1.507
Silicon	0.127
Aluminum	0.594

Table 2. Percentage of metals present in the analyzed region.

From the above, it is possible to conclude that the zinc plate has a large region (lighter region) composed predominantly of zinc with some isolated regions (darker regions) with a predominance of silicon and iron element, possibly in the form of a silicate inclusion.

3.4 Surface roughness

Roughness tests were performed taking into account three parameters: Ra, Rq and Rz. These are the most common parameters for evaluating a metal part made by stamping (LI, 2017). From Fig. 7 it is possible to observe a great change in the surface quality from the plate before the test. However, parameter Ra does not define the shape of the irregularities of the profile.

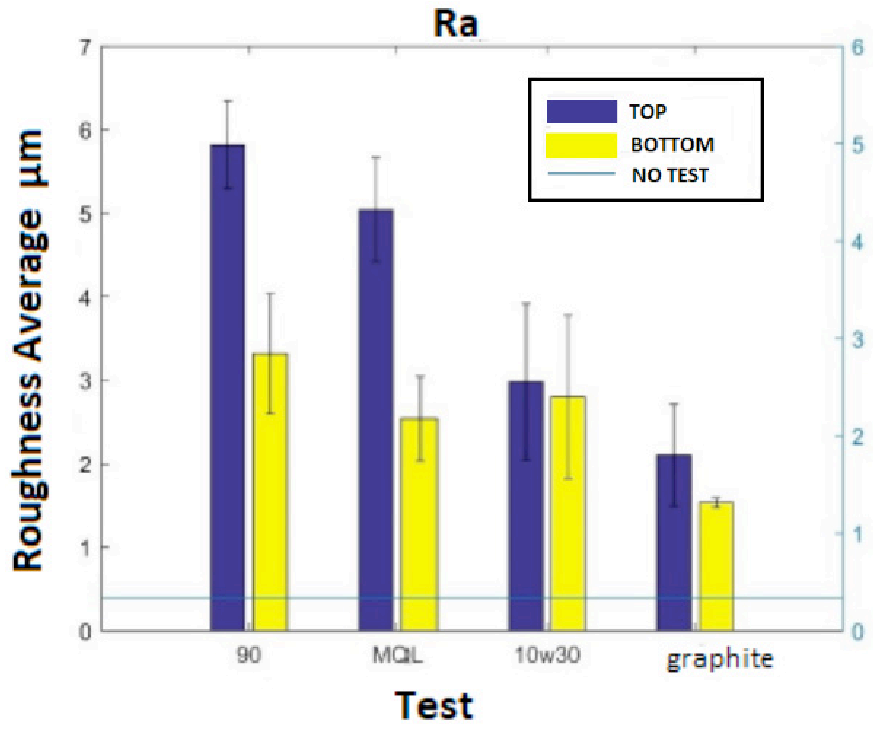

Figure 7. Ra obtained values

As expected, the values of Rq, as shown in Fig. 8, were higher than Ra, because it is more sensitive to a high value of a peak or valley, that is, the parameter Rq accentuates values that deviate from average.

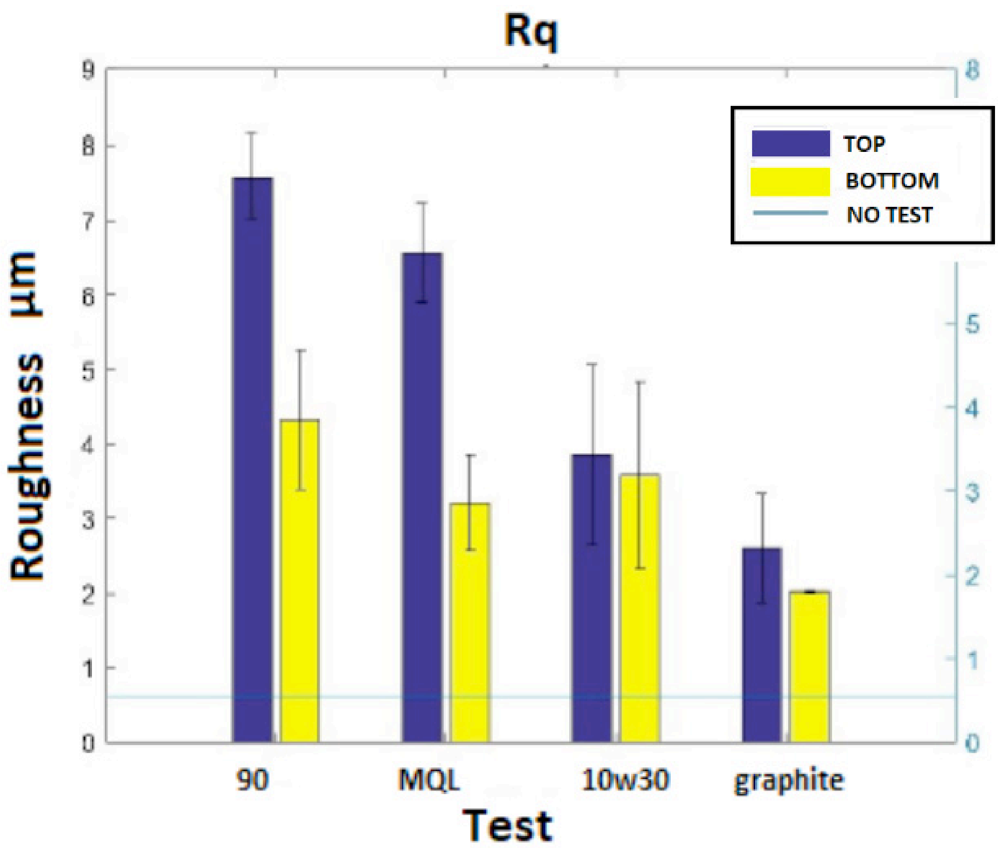

Figure 8. Rq obtained values

Fig. 9 shows the high values of Rz that indicate peaks and valleys in the profile higher than the average roughness. This parameter is more sensitive to changes in finishing than Ra, and captures the valleys produced during tool passage. In this small region, tensions rise above yield strength limit of material, meaning an extreme contact pressure, often accompanied by heat generation.

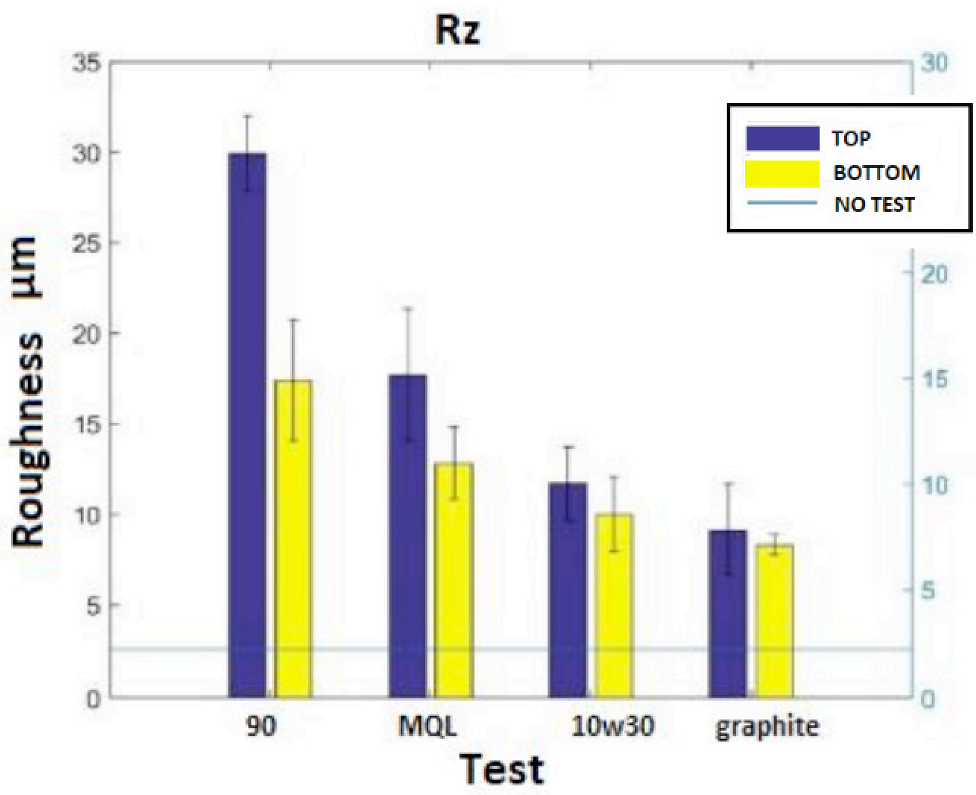

Figure 9. Rz obtained values

A problem during trials was that when the forward speed exceeded the data transmission capacity, bumps happened in the machine because of discontinuity of movement. As a result there were short temporary loss of the second and third degree polynomial interpolation (functions G02 and G03) for an interpolation by straight segments (G01 function), during a few milliseconds along the test, resulting in an undesirable quality finish, with vertical wall striations (SOUZA, 2008).

Another cause for the drop in finish quality is the change in the temperature of the lubri-refrigerant fluid and the consequent alteration of its properties. There is also the presence of particulates that are released from the sheet during the forming process and are retained in the fluid, being able to scratch the part's surface.

3.5 Metallographic analysis

Figure 10(a) shows the transverse section of the untested sheet. Its blue-like color is typical of zinc sheets, but the more intense surface color might indicate a great quantity of concentrated energy because of the plastic deformation occurred during the cut. Figure 10(b) shows the upper part of the untested sheet. In this case, the presence of plastic deformation is not noticeable, only the microstructure of zinc with darker points, probably made up of silicates.

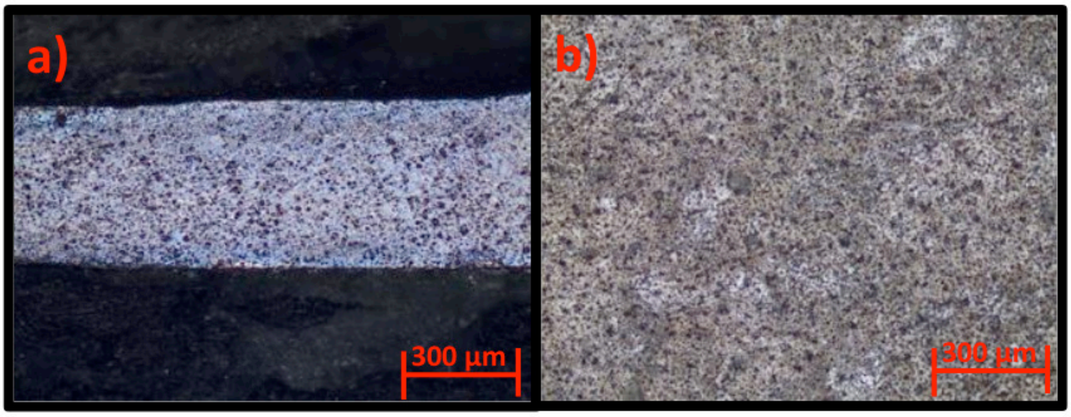

Figure 10. a) View of the transverse section of the sheet before the essay. b) Top view of the sheet before the trial.

Fig. 11(a) shows the microstructure of sample lubricated with SAE 10W30 oil. From the image, it is possible to observe a more deformed (upper) region, in which there was a higher concentration of energy because of the stamping test and, therefore, more etched by the reagent. The deformed region is about 90 micrometers length and the microstructure is mainly composed of zinc and silicates (darker region). Fig. 11(b) shows the microstructure for the test with the lubricant oil SAE 90. The depth of deformed region was about 70 micrometers. Considering the viscosity of the fluid as a resistance to the internal shear, it is possible that the SAE 90 oil being a more viscous fluid than the 10W30 it was able to absorb more deformation, resulting in a lower deformation at the sheet.

Figure 11(c) shows a micrograph to the test with MQL. In this test, the deformed layer had a slightly lower depth than commercial automotive oils, with 55 micrometers. Moreover, Figure 11(d) shows the result for the test with the solid lubricant. This test presented the deformation with lower depth. A hypothesis for this result is that the presence of graphite is an additional component, responsible for absorbing part of the energy by the deformation caused by the shear of its lamellar structure, due to its weak Van der Waals links. Besides, the effective lubricating effect of graphite might also be associated to the better surface quality achieved, diminishing the pressure applied by the tool during its passage through the sheet.

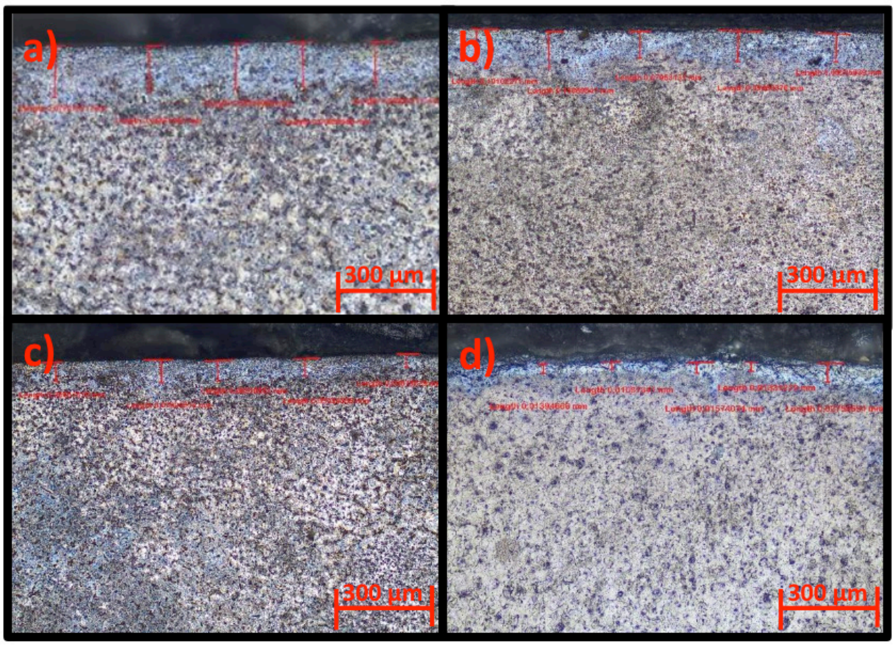

Figure 11. a) SAE 10w30 oil b) SAE 90 oil c) MQL d) Solid Lubricant

4 I CONCLUSION

Through practical experiments, it was possible to demonstrate that it is possible to adapt resources used in machining, such as a CNC machining center, tools and software for the production of geometries employing incremental sheet forming of pure zinc.

This material exhibited a suitable behavior for stamping, with great ductility and elongation, though it presents a low mechanical resistance when compared to other metals such as steel, for example (KONDRATIUK, 2011). The planar anisotropy results indicate that there is a great variation in the mechanical response between the longitudinal and transverse directions. This fact suggests that the use of a previous annealing process could improve even more the formability of the material (LU, 2016). As expected, the process generated increased surface roughness. This increase was, however, smaller at the end of the process, mainly due to the better lubrication conditions at the end of the test, since the cone geometry itself concentrated more lubricant in the shaped region, similar to the findings of Filice (2013). Among the four experiments, the graphite lubrication presented a slightly better surface quality than the others did. The lubrication by MQL was adequate, with results close to the others, proving its effectiveness as lubricating medium. Taking into account the low quantity used, this option is advantageous when analyzed from an economic and environmental perspective. For commercial oils, the less viscous lubricant resulted in a better surface finish as it has a better ability to “wet” the surface and establish a good thermal contact, even though the tests point to a deeper deformed region.

The residual deformations analyzed by metallography analysis indicate that the viscosity of the fluids was directly correlated with the depth of the plastically deformed zone, in accordance to studies of Gatea (2016) and Maqbool (2019). This can be explained by the fact that higher viscosity usually generates higher lubricity, as observed in the tribological system in question. The use of graphite as a solid lubricant further aided the tribosystem lubricity, reducing even more the depth of the plastically deformed zone and improving surface quality.

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