NUMERICAL STUDY FOR LUBRICATION EFFECTS IN METAL FORMING THROUGH THE PROCESS OF BARREL COMPRESSION

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Abstract. In metal forming process, friction is one of the most important factors, as it has a great influence on the shear stress behavior. The shear stress pattern determines the material's properties, structures and energy requirements. In addition, the importance of friction analysis also arises from the efforts to which the material is subjected and from the reaction force on the machinery used, with direct implications for the efficiency of the manufacturing process, the cost and the time employed. Therefore, analyzing ways to reduce the damaging consequences of friction is extremely important. In this sense, the analysis of lubrication becomes too relevant since, through the reduction of friction, it is possible to increase the efficiency in the metal forming process.

Thus, the present study aims to relate the effect of lubrication on the shear stress of the specimen with the analysis using the computational method of Finite Elements in the Barrel Compression process. For this purpose, the friction coefficients of the main lubricants on the market were used and the effects on the test results were simulated.

Therefore, numerical analysis was performed in the Ansys Structural Analysis® software environment. Thus, the CAD models for the specimen and for the test matrix were created. In addition, a mesh evaluation was made, scoring the effects arising from the precision change. Besides, the boundary conditions were also scored, using the various tools that the software offers. It should be noted that the program resolution algorithms were verified, as well as their convergence criteria.

Finally, in possession of the computer simulation results, their validation is sought by comparing them with the theoretical expected for the same test, but in the absence of lubrication. In this way, gains from surface lubrication are quantified and the extent to which the change in lubricant causes a relevant consequence in shear stress is also measured. This article, therefore, seeks to be another source of research in the promising area of metal forming analysis.

Keywords: Metal forming process, lubrication, barrel compression

1 Introdução

The processes of mechanical conformation have contributed significantly to the development of modern society, especially after the Industrial Revolution [1]. Since then, several industries have acquired capabilities such as the interchangeability of the produced parts, as observed in Colt revolvers in 1851 [1],[2].

In addition, technological advances have made it possible to develop new techniques and studies for the increase in growth of the existing manufacturing processes efficiency. In this context, a field of study stands out: the evaluation of the friction and lubrication effects in the mechanical forming processes [3],[4]. Since friction can cause variations in temperature and characteristics of the material to be used, this area was created to determine the results arising from friction during the manufacturing process.

For the evaluation of friction, the Barrel Compression (BC) will be considered. It allows the evaluation of friction without the need to delve into the mechanical properties of the material [5]. Thus, there are studies that prove the possibility of applying the BC method for the evaluation of the friction effect [6]. Therefore, it is important to further study this theme with numerical simulations and analysis according to the literature of this test.

Furthermore, the study in the area of lubricants is extremely important for the optimization of mechanical conformation processes. In this context, the current industry recommends the use of ideal fluids in order to reach the degree of satisfaction expected for the final product [7]. Thus, there are several researches in this area as that of the bending under stress test to assess the relations of friction with the properties of lubricants in the deep drawing technique [8]. In addition to this, it can also be named other studies that analyzed the effects of finishing with lubricants [9].

It is natural, therefore, to extend the studies previously carried out for the Barrel Compression test, evaluating the effects arising from the presence of lubrication. Regarding the evaluation of friction, analytics methods are important for the quantitative analysis of the friction condition. However, the finite element method has been considered the most accepted method of analysis [10]. Based on this, it is intended to also measure the contribution that is obtained through the precision of the studied mesh.

Finally, this study will use lubricants with different values of friction coefficient (μ), with the aim of applying commercial lubricants in research on shear stress variation with μ. Such analysis will consider the friction coefficient modeling [11], [12] and will be performed in the *Ansys*® software with the computational package *Static Structural Analysis*® to achieve the desired results.

2 LITERATURE REVIEW

2.1 BARREL COMPRESSION

Figure 2.1 demonstrates the compression process of a cylinder with radius R_0 and height H_0, known as barrel compression.In this test, the cylinder is compressed by two horizontal planes, until the formation of the rounded profile side.Thus, friction is measured through the degree of rounding (b), which is given by the Equation 1 [13], and its terms described by equations 2, 3 and 4.

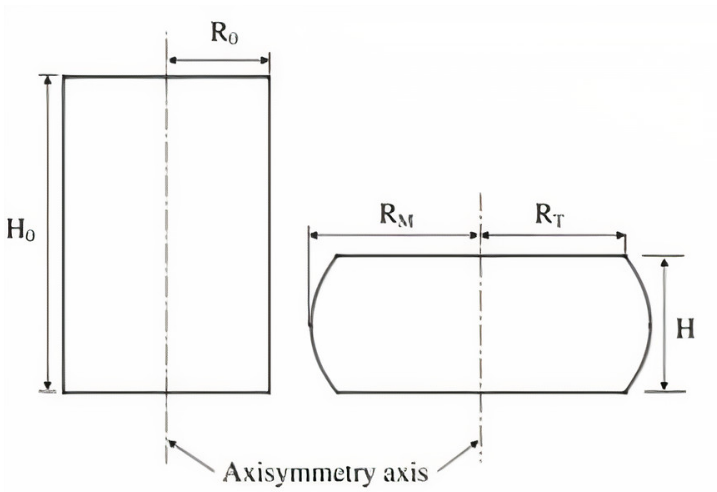

Figure 2.1. Representation of the compression process with barrel deformation [3].

Based on Figure 2.1, we have:

$$b = 4\frac{\Delta(RH)}{R\Delta H} \tag{1}$$

Which:

$$R = R_0\sqrt{\frac{H_0}{H}} \tag{2}$$

$$\Delta R = R_M - R_T \tag{3}$$

$$\Delta H = H_0 - H \tag{4}$$

Knowing, therefore, that the degree of rounding is affected by the friction condition and it has a direct relationship with the shear stress exerted on the specimen [14], the influence of the use of lubricants can be evaluated in shear stress on the model tested using this method. It should be noted that the software used performs these calculations, so there is no need to perform them manually.

2.2 FINITE ELEMENT ANALYSIS

The Finite Element Method is widely used in computer simulations to make predictions, from a model of a certain body. Its application not only saves engineering professionals several hours, who would have to carry out the entire study manually, but also increases the ease of change in the experiment from simple parameter changes.In this way, time, personnel and even financial resources are saved, making the projects even more viable [15].

The finite element analysis methodology consists of dividing the system to be evaluated into small elements according to the desired results and the dimensions of the system as a whole. After this division,each of these parts will be evaluated individually according to the boundary conditions and according to the differential equations that govern the phenomenon studied in the simulation.

The method therefore proposes that an infinite number of unknown variables be replaced by one limited number of well-defined behavioral elements. These subpartitions can be presented from different shapes, such as triangular, quadrilateral, among others. The selection criteria depends on the type and the dimension of the problem [16].

For the finite element analysis to be effective, the mesh convergence must be verified, that is, the size and shape of each of these elements needs to be consistent according to the result to be achieved. A more accurate evaluation is obtained for smaller element sizes, however it should also be taken into account the processing time that will be required.

2.3 LUBRIFICANTS

Lubricant, briefly, is a thin film of low shear strength material. For example,there is the grease, which aims to change the friction conditions in the contact area between two surfaces [21].

Furthermore, lubrication can occur in three different ways [22]. The first of these is limit lubrication, marked by permanent contact during movement. The second form is the mixed one, in which the contact between the surfaces becomes sporadic. Finally, there is the hydrodynamics, marked by the separation of the surfaces by the lubricant.

For this article, limit lubrication will be considered, using three different commercial lubricants. For 6061 Aluminum, there are the following friction factors (μ):

- Aerodag: 0,033 [17];
- Teflon: 0,037 [17]; and,
- Olidag: 0,075 [18].

For comparative effects with the listed values, the friction coefficient for that same aluminum alloy without sanding is $\mu = 0,75$ [19] and for the ideal situation, that is, without friction, $\mu = 0$.

3 METHODOLOGY

The analyzed geometry was generated by the rotation around the vertical axis shown in Figure 3.1, with the dimensions described in Table 1. The geometry is three-dimensional (3D) and composed of 3 bodies, two representing the lower and upper part of the matrix that will compress the specimen, so that they have axi-symmetric symmetry. In the contact area of the model with the upper and lower bodies, a friction condition was applied, whose value used is according to values of commercial lubricants applied to the model material.

The analysis performed, therefore, compares the effect of the friction coefficient on the body's shear stress for the values of 0.01, 0.033, 0.037, 0.05 and 0.075. In addition, the final mesh chosen for the system has 1458 elements and 8012 nodes. It was not possible to use a finer mesh to represent the problem due to hardware and software conditions, this being the best available.

The configuration will have 6061 Aluminum as body material, with sample compression in 5 mm due to to the downward displacement of the upper horizontal plane. It is also noted that the ratio between the diameter of the cylinder and its height is equal to $2/3$.

In addition, to collect the results, the software interface is used to investigate the distribution of the shear stress in the mesh, recording the maximum, minimum and average value of this stress in the body.

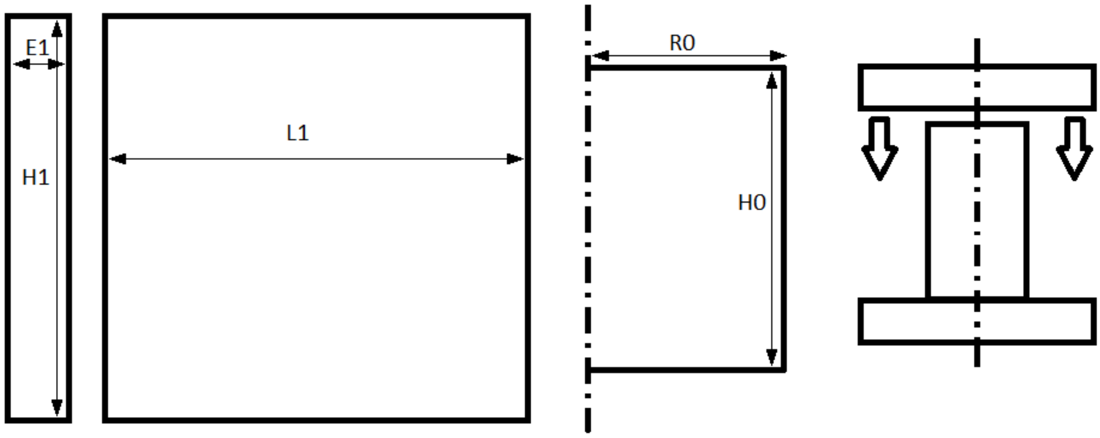

Figure 3.1. Geometry used and dimensions reference

Table 1. Dimensions of the geometry used.

Parameters	Value
R0	10 mm
H0	15 mm
L1 and H1	30 mm
E1	5 mm

Finally, it is qualitatively observed the stresses under the cylinder face and the way the mesh undergoes deformation, since large deformations favor the mischaracterization of the mesh elements.

4 RESULTS

Table 2 shows the values obtained for the maximum, average and minimum shear stress, as a function of the friction coefficient, respectively in the 2nd, 3rd, 4th and 1st columns. The fifth column contains the ratio between the maximum and average shear stress, allowing it to demonstrate the level of uniformity in the distribution of efforts in the body. Lastly, the last column shows the difference between the maximum shear stress observed in the simulation and the maximum shear stress for the respective row.

Table 2. Simulation results of the shear stresses (Pascal).

μ	Maximum	Average	Minimum	Ratio	Difference
0,075	1,51E+10	8,77E+09	5,60E+09	1,72	
0,05	1,46E+10	8,81E+09	6,25E+09	1,66	-3,46%
0,037	1,43E+10	8,83E+09	6,66E+09	1,62	-5,38%
0,033	1,42E+10	8,83E+09	6,76E+09	1,61	-5,86%
0,01	1,30E+10	8,88E+09	7,27E+09	1,46	-1,40%

From table 2 the graph in Figure 4.1 was elaborated. In this way, it is possible to observe, with greater clarity, that the decrease in the friction coefficient resulted in a decrease in the maximum shear stress. However, it was observed that the average stress remained relatively constant.

This result indicates that, although the vertical deformation was the same, the lateral displacement was facilitated by decreasing friction. Therefore, reducing the efforts on both the machine and the workpiece. Furthermore, a reinforcement of this theory is evidenced with the increase of the minimum shear stress, which grows over time that the maximum decreases and there is a significant decrease in the ratios in the fourth column of table 2.

In addition, Figure 4.2 shows both the shear stress and the deformation that the element underwent when being compressed. Observing the mesh in question, there is the rounding of the cylinder side, due to the flow side of the inner material.

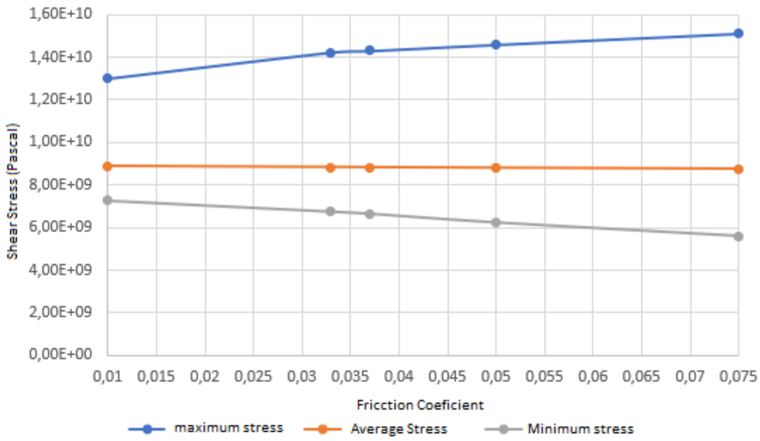

Figure 4.1. Shear stress curves by friction coefficient.

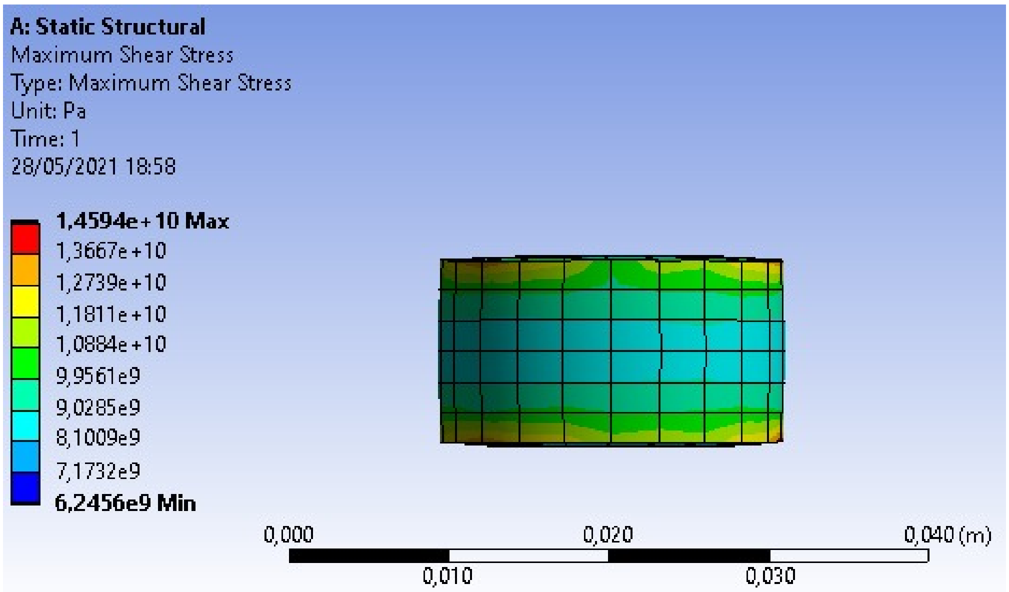

Figure 4.2. Shear stress contour for μ equal to 0.05.

It is also possible to observe that at the end of the faces there is a significant concentration of tension. That happens due to compression of the center of the specimen, which causes the material in this region to tend to shift laterally and then vertically, reaching the lateral deformation that occurs on the face. Consequently, this region is susceptible to shear stresses up to 72% greater than the rest of the body.

The mesh, thus, behaved as expected, with no element suffering excessive deformation to the point of misconfiguring the geometry, which would invalidate the results. With regard to the mesh of the others in the matrix, this was considered rigid and served only to compress the object of study.

5 CONCLUSIONS

This work performed evaluations of different boundary conditions for behavior modeling of the Barrel Compression process. It was observed, therefore, that the software used actually manages to reproduce the circular deformation effect on the side face of the cylinder studied, obtaining results consistent with the theory.

According to the lubricant used for the simulation, it was possible to obtain the results for the maximum value shear stress when varying the value of the friction coefficient between the sample and the matrix.

Furthermore, the computer simulation allowed us to observe that the increase in the friction coefficient causes the maximum shear stress increase in the specimen, due to the greater ease of the part to deform laterally. It was also observed that the evaluation of the results was satisfactory, since the meshes used did not lose quality throughout the simulation.

Lastly, future studies may consider other conformation processes for the analysis of influence of the chosen lubricant with shear stress, such as Double Cup Extrusion (DCE). Furthermore, it can be also explored the proof of the results obtained by numerical analysis through reproduction laboratory of the experiment with the use of commercial lubricants.

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