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THE INFLUENCE OF VEGETABLE LUBRICATION WITH SILICA MICROPARTICLES ON THE DEEP DRAWING FORCE

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Abstract. *The success of a deep-drawing operation is strongly dependent on the selected lubrication. Lubricants are traditionally formulated from mineral oils that are harmful to workers' health and of difficult discard. The potential of vegetable oils as lubricants, in deep-drawing processes, is already proven by recent studies. However, it is needed to investigate solid additives that can complement the properties of these oils. The deep drawing of composite materials has high applicability for the industry and can provide multifunctional needs that may not be found in conventional steel sheets. The present work is an experimental analysis of vegetable oils with silica microparticles performance, applied in the deep drawing of a layered sheet composite in a sandwich arrangement. Castor, cotton, and canola oils were used as the base fluids. Two samples of silica with two different particle sizes and three different concentrations were used as solid additives. A cup with an internal diameter of 22 mm and a height of 10 mm was the final product obtained from the deep-drawing process. The effect of lubrication on the process was analyzed by ANOVA, investigating the maximum stamping force. The maximum deep drawing forces were only influenced by the different types of silica.*

Keywords: *deep drawing, lubrication, vegetable oils, silica micro particles, sandwich composite*

1. INTRODUCTION

The forming process of metallic bodies is understood as the process of modifying the shape of a metallic body to another defined shape. The relevance of studying the metal forming processes is due to its importance on the production of metallic components, which are submitted to such processes in one or more stages. The factors that control the sheet metal forming process are diverse, and might be from mechanical or metallurgical natures. Regarding to mechanical factors, the following are relevant: the shape and dimensions of the part, the forming machine (the type of press), the shape and dimensions of the tools (punch and dies), and the lubrication conditions (BRESCIANI FILHO et al., 2011).

Metal Forming lubricant formulations are generally consisted of a petroleum-derived oil also called mineral oils, which are also composed of additives of various types (BLAU et al., 1992). Although mineral-based lubricants are the most used in the deep drawing process as it is in many other metallurgical processes, it is known that their uses causes concerns related to the environment and the operator's health. Mineral oils fall into the category of hazardous and potentially toxic products. In addition, they are substances derived from a non-renewable source and their use generates hard-to-dispose waste (RIBEIRO et al., 2016). Replacing mineral oils with vegetable oils reduces the mentioned impacts, as they are biodegradable, derived from renewable sources, and cause no danger to the operator.

Cavalcanti (2018) points out that vegetable oils have good lubricating properties related to viscosity when compared to the conventional mineral oils. Pinto (2015) has compared the performance of a mineral lubricant and vegetable oils from castor, cotton, corn and linseed in the deep drawing process of a high-strength low-alloy steel (HSLA). The drawability, roughness and thickness variation, were evaluated with the objective of proposing a replacement of mineral lubricants by vegetable oils. It was confirmed that castor and cotton oils presented equal or better results than the analyzed mineral lubricant for the mentioned parameters, confirming to be suitable for the metal forming process.

Solids such as graphite, molybdenum disulfide, metal powders, metal oxides, metal halides, mica and polytetrafluoroethylene are already used as lubricants suspended in oil or water for certain operations such as extrusion and forming. For this process solid particulates in the form of very fine powders are kept in suspension by mechanical agitation or emulsifiers (BLAU et al., 1992). In recent studies (PEÑA-PARÁS et al., 2018; SUI et al., 2018) of these solid additives, silica is identified as an ecological material to be a potential alternative as a lubricant solid additive.

Among its benefits, silica is also mentioned for presenting good economic efficiency due to its low cost and ease of access.

Therefore, silica may be first identified as an abrasive particle and may be questioned about its lubrication proprieties it has a potential role in lubrication proved by previous studies (LEE et al., 2009; SUI et al., 2018; WU; TSUI; LIU, 2007). Peña-Parás et al. (2018) studied the effect of adding nano- and micro-scale titanium dioxide particles as a solid additive to a synthetic lubricant. In their study, they changed the particle size and roughness of the sliding surfaces to characterize the interrelated effects of these two parameters. The results suggested that there is an ideal particle size that will minimize friction and wear for a given surface roughness. The analyzes support previous proposed mechanism (LEE et al., 2009; WU; TSUI; LIU, 2007) for solid additives, in which the particles fill valleys in sliding surfaces. In this context, particles smaller than the surface roughness are more likely to perform this function.

Recently, layered metal sheets have been developed in the automotive and steel industries to facilitate the manufacturing process of various components and reduce fuel consumption. Layered sheets, also called sandwich or layered composites, have the potential to utilize complementary properties of the original materials and thus improve their functionality. Metal/polymer/metal sandwich materials provide an innovative replacement for commercial sheets because of their lightweight potential (HARHASH et al., 2018). There are multifunctional needs that steels may not fulfill, in these cases layered sheets can offer significant advantages. This combination of materials (the composite) results in improved functional properties such as thermal or electrical conduction, wear resistance, and corrosion resistance. The deep drawing of laminated composite materials, therefore, proves to be a field of high applicability for the industry and is being investigated in recent studies. Baek et al. (2018) and Harhash et al. (2018) presented studies on deep drawing of metal/polymer/metal sandwich sheets, where the behavior of these composites in the deep drawing process of cup shape products were analyzed.

Based on previous studies (CAVALCANTI, 2018; PINTO, 2015; RIBEIRO et al., 2016) proving the feasibility of replacing mineral oils with vegetable oils in the deep drawing process, this research was carried out with the objective of investigating the effect of the addition of micro particles of silica in different vegetable oils in order to propose a more ecological lubricant for the deep drawing process. Thus, contributing to the study of replacing the widely used mineral oils in the metal forming industries.

2. METHODS

The present work adopted the complete factorial design of experiments randomized by levels to facilitate the conduction of the deep drawing operations. Statistical analysis was used to access the influence of each lubrication condition on the deep drawing force through an Analysis of Variance (ANOVA), and assuming a confidence level of 95%. Table 6 presents the chosen input factors and their respective levels.

Table 1. Factors and input levels.

Factor	Levels	Values
Oil	**3**	**Cotton; Canola; Castor**
Silica (mesh)	**2**	**450; 500**
Concentration (%)	**3**	**1; 3; 5**

The tool was manufactured at the Machining Laboratory of the Mechanical Engineering Department (DEMEC) of the Federal University of São João del-Rei (UFSJ), in ABNT 1045 steel and submitted to hardening and tempering treatments. The Figure 1(a) shows the parts of the tool, where the following can be observed: the die (1); the blank holder (2); the punch guide (3); the base of the die (4); the punch (5); and the blank, with the copper side up in (6) and the SAE 1006 steel side in (7). Figure 1(b) shows the assembled tooling.

(a) (b)

Figure 1. Stamping tool. (a) Disassembled tooling. (b) Assembled tooling.

The blanks (workpieces) were manufactured at the Machining Laboratory at UFSJ, from SAE 1006 steel sheets and ASTM C11000 electrolytic copper, both 0.6 mm thick, separated by a thin film of Polyvinylidene Chloride (PVC), 0.01 mm thick. The steel and copper discs were manufactured separately with dimensions of 35 mm in diameter and 0.6 mm in thickness. The Figure 2 shows the final disposition of the layered sheet blank, where both can be seen: copper (1) and steel (2), with the intermediate layer of PVC.

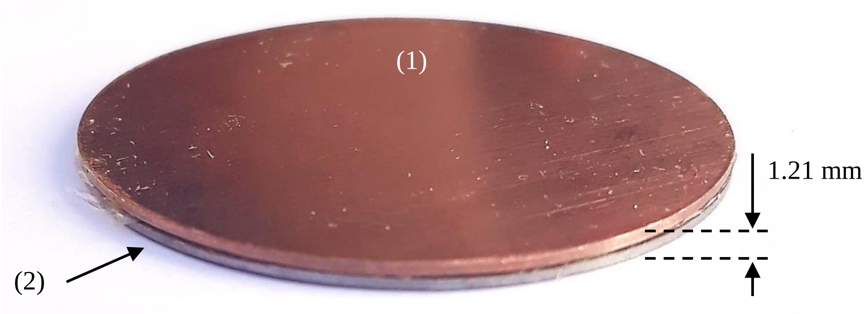


Figure 2. Copper-PVC-Steel composite blank for the deep drawing process.

The lubricant mixtures were carried out at the Materials Laboratory at UFSJ. Canola, cotton and castor oils were used as the base oils for the lubricant mixtures. The analyzes of the silica samples were performed on a Scanning Electron Microscope. The mixtures were calculated to contain 1%, 3% and 5% of silica micro particles (mass percentage) for each vegetable oil, as mentioned on the table 1. For weighing the materials, a Bioprecisa® Electronic Analytical Scale was used, Figures 3 (a) and (b). During weighing, a tolerance interval of ± 0.05 g for oil and ± 0.005 g for silica was considered. The mixtures were carried out using a Thelga® Magnetic Stirrer Mixer, without the use of heating for about 5 min, Figure 3 (c). For the lubrication, the blanks were completely immersed in the lubricant mixture. The mixtures were kept under stirring during the experiment to guarantee the suspension of the silica particles in the mixture during the application.

(a) (b) (c)

Figure 3. (a) weighing the castor oil, (b) weighing the 450 mesh silica microparticles for 3% by mass mixture, (c) mixture of oil and silica under stirring.

The deep drawing tests were performed on a Shimadzu Autograph AG-X Plus Universal Testing Machine with a maximum capacity of 10 tons, located in the Composites Technology and Innovation Center at UFSJ. The displacement speed of the equipment was 30 mm/min with the controlled ambient temperature of 23°C. The force values were collected during the whole experiment and the maximum force (Fmax) was the selected output to be analyzed at this study. The final product obtained by the deep drawing of the studied composite is shown in the Figure 4, with average dimensions of 12 mm for the height and 20 mm for the inner diameter.

Figure 4. Deep drawing final product.

3. RESULTS AND DISCUSSIONS

For the analysis of the deep drawing force, the maximum force values were measured. An example of the evolution of the deep drawing force by the displacement of the punch is shown on the Figure 5 with the following lubrication conditions: castor oil lubrication with 1% of 450 mesh silica microparticles. In Figure 4, the presence of two force peaks can be noted. The peaks were also noticed in the analysis of the deep drawing force curves of the other studied lubrication conditions. The existence of a second peak can be related to the hardening of the material as mentioned by Rodrigues and Martins (2010). Although those peaks can also occur in deep drawing of the same material due to the position factor, when working sheets of different materials, the peaks of maximum force can be also related to the difference of the yield point of the different materials.

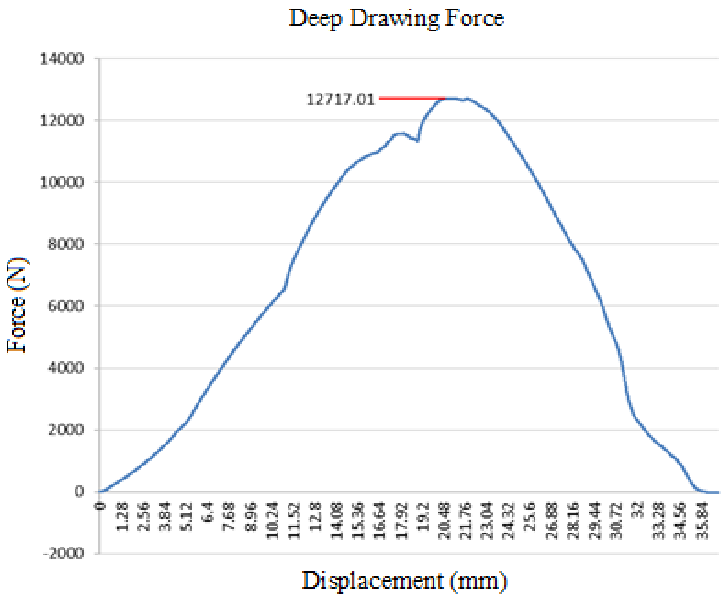


Figure 5. Force X Displacement curve for deep stamping (Treatment: Castor oil; 450 mesh; 1%).

Paying a close attention to the evolution of the deep drawing force, it is noticed that the first phase is characterized by the highest rate of increasing force. This region of the Force x Displacement graph is characterized by the increase in radial stress and the increasing inclination of the conical zone of the cup that is being formed (RODRIGUES; MARTINS, 2010). The deep drawing force reaches the maximum value F_{max} as soon as the material located at the die edge and ate the flange start the plastic deformation. The plastic deformation starts when the intensity of the shear component of the applied force in the plane and in slip direction reaches the material's yield point. From the beginning of the plastic deformation the material is flowing into the matrix, characterizing its permanent deformation (CALLISTER; RETHWISCH, 2010; RODRIGUES; MARTINS, 2010).

When considering the hardening effect of the material, however, the maximum force will not occur at the beginning of the plastic deformation, but a little later. For Rodrigues and Martins (2010), this displacement of the point of maximum force is justified by the increase in radial tension, which will be bigger than the decrease associated with the reduction of the drawing ratio. As a general rule, the follow up plastic deformation will require a different level of stress than the initial one.

To verify the feasibility of analysis of variance (ANOVA) of the maximum deep drawing force values, a normality test of the residues was performed. The variables were evaluated for their main effects (Oil, Silica and Concentration), for their second-order interactions (Oil*Silica, Oil*Concentration, and Silica*Concentration) and third-order interaction (Oil*Silica*Concentration). The ANOVA analysis showed that, for first-order effects, only the silica factor had a significant effect on the maximum deep drawing force. The other variables did not show significance according to ANOVA as well as any interactions. Figure 6 shows the main effect chart of the variation of silica types, 450 and 500 mesh, for maximum stamping force.

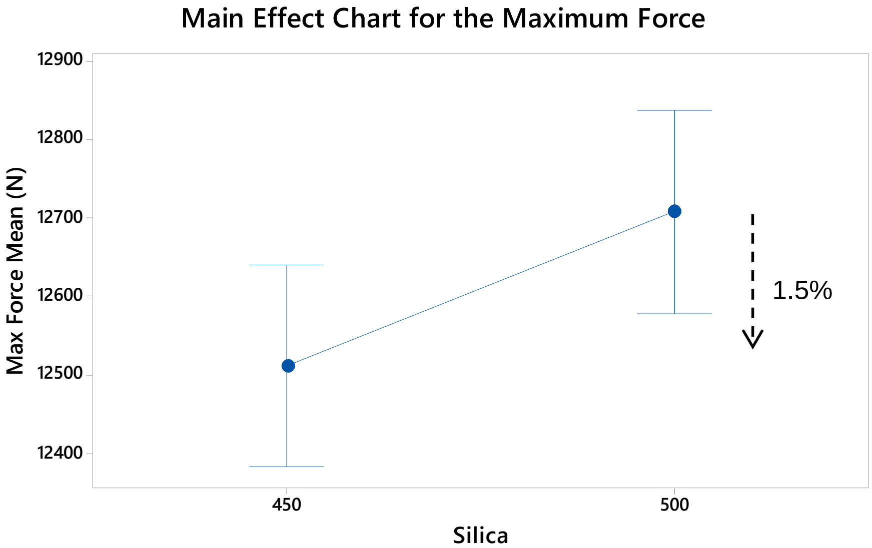
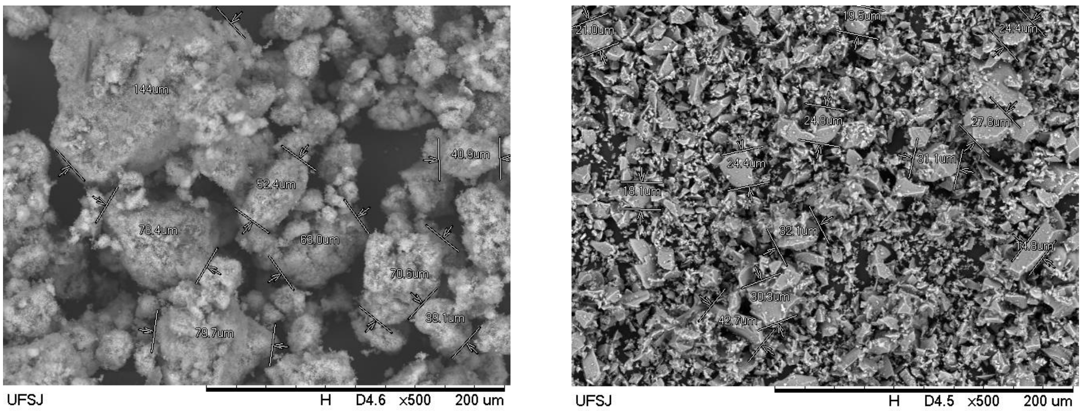


Figure 6. Influence of silica types on maximum stamping force (Main effect chart).

The maximum force values found in this study are consistent when compared to previous values shown by Rosa (2019), for deep drawing cups of the same geometry. When applying a lubrication on the deep drawing process, it is expected that it will act to reduce the dynamic friction between the blank and the die. Therefore, it is expected that the lower friction values influence the deep drawing force, causing it to decrease. In this way, it is possible to expect a reduction in the energy spent in the process, less wear on the tool and an improvement in the quality of the final part. For the effect of the variation of the type of silica in the stamping force, shown in Figure 6, it is noted that the silica with the largest particle size, 450 mesh, generated a lower average deep drawing force, 1.5% lower than the upper average. The Figure 7 shows the comparison of the morphology of the silica samples that may help understand the fact that smaller silica sizes have result in higher deep drawing forces. The finer 500 mesh silica had a less rough surface, but with an angular aspect and the presence of very evident edges, which may have influenced the kinetic behavior of solid particles in the lubricant mixture during the deep drawing process.



(a) (b)

Figure 7. Photograph taken by Scanning electron microscope (SEM). (a) of a 450 mesh silica sample. (b) of a 500 mesh silica sample.

4. CONCLUSIONS

The present study has shown that the maximum deep drawing force was only influenced by the silica type. Therefore, the largest particles of silica of 450 mesh with subangular geometry was chosen as the best condition by showing a significant reduction for the average maximum deep drawing force. More investigations should be taken for the consideration of the proposed lubrication mixture for the deep drawing process. Therefore, as a part of a master dissertation this work intends to continue investigating the influence of the lubrication by analyzing the final cup obtained from the deep drawing process.

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6. RESPONSIBILITY NOTICE

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