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THE INFLUENCE OF THE LUBRICATION IN THE SURFACE ROUGHNESS INCREMENTAL SHEET FORMING PROCESS

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Abstract. *In order to successfully stamp metal plates, one must take into account some variables, such as material properties, strain hardening coefficients and anisotropy, tool geometry, punch interface lubrication - sheet metal, resignation speed, among others . All these variables are interrelated. This work deals with the incremental sheet forming process in automotive structural extra-deep-drawing steel (EDDS), starting from experiments to characterize the material properties regarding this technique processing; The diameter of the stamping tool being set as 12 mm, with constant spindle speed and steady speed increments. The purpose of this study is to demonstrate that the lubrication directly effects the mechanism of roughness formation. From experiments with various lubricants: automotive wax, graphite, MQF, Petroleum jelly, and without the use of lubricant. A variation in the surface finish could be observed. Therefore, this work aimed to better understand the formation of the deformation mechanism in the stamping process, evaluating its external surface finish.*

Keywords: *surface finish, incremental stamping, lubricant, roughness.*

1. INTRODUCTION

Competition in the capitalist world spells out the rules in all spheres and with the industry is no different. In this environment, there are increasingly attempts to create more economically productive manufacturing processes. This concept aggregates time, process and raw materials savings. As a rule of thumb, in a factory productive scenario, a process is only viable if it is applicable on a large scale; yet, there is a gap in this line of thought, which demands some attention. Prototypes and low-volume production parts are usually expensive due to the attention and time they require for their manufacture. In the development of dies and deep conformation operations, especially when there is a need for the development of new products, production on a small scale and/or complex geometries. A solution that has been increasingly feasible and with excellent conformation limits is the Incremental Sheet Forming (ISF), in which a tool controlled by a CNC machining center applies a located force in order to perform a punctual plastic deformation, being well accept when the production is dictated by low-volume manufacturing and highly complex parts.

Jeswiet (2001) demonstrated that this process is used to mold sheet metal into complex shapes without the use of dies, using for this a metallic punctual contact tool, mounted in a machining center, to plastically deform a specimen, by moving the specimen and/or the tool, mainly in the vertical plane. The process generally called Incremental Sheet Forming, it is also known, when the forming tool is of single contact, as Single Point Incremental Forming (SPIF), or, depending on how the piece is formed (internally or externally), the process can still be called Negative or Positive. According to the geometry, it can also be called Symmetric or Asymmetric. Unless stated otherwise, this article deals with the application of SPIF process, Negative, Symmetrical and without the use of dies.

According to Patrício (2011) the theoretical foundations of incremental stamping just recently began to be object of attention of the international scientific community, since that during the first half of the 2000’s, the knowledge that they had about it was only the one obtained experimentally. One of the critical steps of the feasibility of its use is the characterization of the material, which must support certain states of tension without breaking.

Regarding the field of surface finish, Jeswiet and Hamilton (2010) investigated the effects of high speeds and feeds on the roughness of the external part (no contact with the tool), where commonly occurs the "orange peel" effect. It was found that the occurrence of this effect is mainly due to the tool radius and the vertical increment. However, other factors such as material, thickness, inclination angle and rotation speed possibly have influence on both internal and external roughness.

2. INCREMENTAL STAMPING

The process, generally called of Incremental Sheet Forming is also known, when the forming tool has one point contact, as Single Point Incremental Forming (SPIF). When it has two-point contact, as Two Point Incremental Forming (TPIF) or yet, depending on how the piece is formed (internally or externally). The process can also be called "Negative or Positive". It must be emphasized the possibility of the existence or lack of existence of dies, which, when used, can be made of ordinary materials like wood, for example.

The work of Reddy and Cao (2008) illustrates, as seen in Fig. 1, the main variations of Incremental Forming.

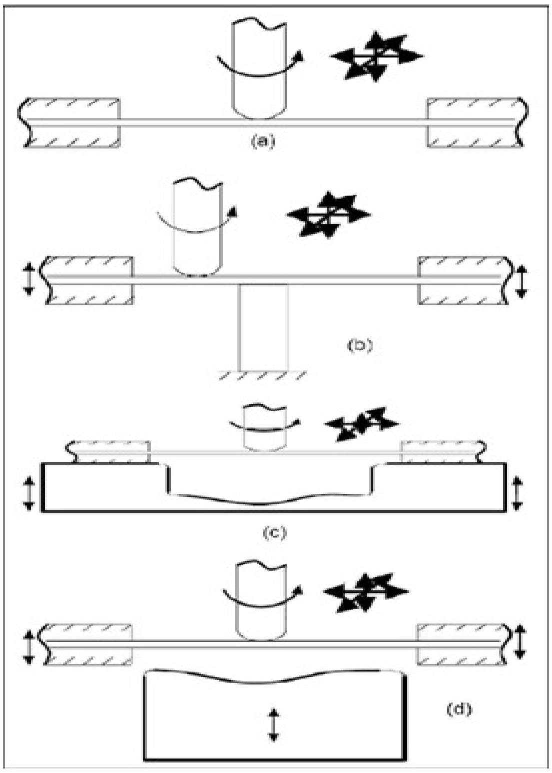

Figure 1. Variants of Incremental Stamping. In (a), SPIF, negative without array.In (b), TPIF positive and without die.In (c), SPIF, negative dies .In (d), SPIF, and positive die(REEDY; CAO, 2008).

The tool is initially positioned on the piece to be obtained, then moving through a predetermined trajectory, according to the final form to be achieved. At each cycle, there is a deformation increment to be applied.

The tool, of generic profile (with a cylindrical or tapered rod, with spherical or semi-spherical tip), produces a plastic deformation localized in a small region of the plate and, in order to carry out the process in an incremental form, it is necessary to verify and control its primary parameters: tool's trajectory, deformation increment, working angle and plate thickness. Fig. 2 illustrates the process as a whole.

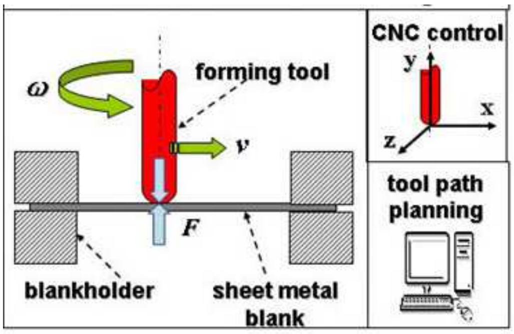

Figure 2. The basic elements of incremental sheet forming (AISF) Adapted J. Jeswiet (2005).

3. LUBRICANTS AND LUBRICATION

Lubricant is any solid or liquid material with low shear strength, whose function is to keep separate the surfaces of the tool (punch and dies) of the material to be conformed, reducing the friction.

The performance of lubricants in stamping of parts may have a significant impact on the process, and in some applications of mounting and stretch forming processes.

Dieter (1996) states that lubricants reduce friction by introducing an interface that is more susceptible to shear stress.

Keeler (2001) defines a lubricant barrier as a film that completely isolates the surface of the sheet metal from the die surface (Fig. 3). In order to efficiently form this layer, some properties must be taken into account.

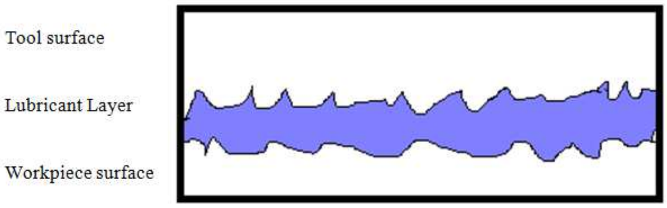

Figure 3. Scheme of a lubricant barrier isolating the surface of the tool and the surface of the sheet metal, Keeler (2001).

Parameters such as viscosity, wettability, extreme pressure additives and efficient cooling may significantly affect the tool life, the part quality, the forming limit and general productivity.

According to Kren (2004), the design and the material of the tool, work piece material, equipment, application method, pre and post-process operation affect lubricant performance.

According to Altanetal (1983) and Kobayashi et al (1989), in forming processes, the flow of material is caused by the compression transmitted by the die to the formed piece. Therefore, the friction conditions in the die-material interface influences the metal flow, the formation of surface and internal defects, the tension and the forces acting during the process.

In order to optimize the performance of the tool, according to Altan et al (2005), is necessary to evaluate the performance of the basic functions of lubricants: control the friction, thus reducing tool wear, guard against "galling" (progressive adherence of the material of the part on the tool), reduce the effort required for forming, reducing the steps of stamping, increase the limits of deformation, protect against corrosion and dissipate heat. The first are performed using lubricating mechanisms. The heat is dissipated through the vehicle used to transport the lubricant.

In dry conditions no lubricant is used on the interface and only the oxide layers present in the die and in the raw material are present. In this case, friction is high, situation desirable only on a small number of conforming operations.

The three lubrication mechanism according to Trivettetal (2004) are:

- Hydrodynamic lubrication
- Lubrication limit
- EP Lubrication (extreme pressure)

The hydrodynamic conditions, according to Klann (2000), exist when a thick layer of lubricant is present between the dies and the work piece. Although it works as lubrication in automotive engines, it contributes little to stamping processes. The efficacy of the hydrodynamic lubrication decreases with increase in the force and temperature between the surfaces. Typically, the temperature and pressure in the piece-tool interface during the stamping process exceed the endurance limit of hydrodynamic lubrication; thus, boundary lubrication, EP lubrication or a combination thereof is required. According to Trivettetal (2004), the hydrodynamic lubricating acts as a film, which separates the surface of the tool from the piece in low-pressure conditions.

According to Trivettetal (2004), the lubrication limit is achieved by using polar additives or emulsifiers that have attraction to the metal surface. This affinity promotes a barrier that protects the tool and the work piece.

Limit lubrication may have oily derivatives such as lard, fatty alcohol, among others, and surfactants, that are active surfaces in the material. Polar additives, added to function as a lubrication mechanism also accentuate the wettability characteristic of the lubricant, securing a continuous layer on the metal surface. Limit lubrication, according to Klann (2000), embodies an important role in the stamping with lubricants, however oils and soaps are inefficient especially above 100 ° C, then they are used in combination with EP lubricants.

There are two types of extreme pressure lubrication EP: mechanical and chemical. Both can efficiently separate part from tool, controlling the friction, reducing the tool wear, preventing "galling" and increasing the forming limit. Typical EP additives are calcium carbonate and molybdenum disulfide.

Unfortunately, mechanical films tend to develop grime on the device and are incompatible with the post-process. Evidently, it will be present, impregnated, in tools with complex geometry

According to Godwin (2004), chemical EP additives such as sulfur, chlorine or phosphorus are used more frequently. They react in the piece-tool interface, forming metal salts acting as sacrifice surface. Chlorine is added to the stamping lubricant to form chlorinated hydrocarbons. During the stamping process, the heat generated in the work piece-tool interface frees the chlorine that reacts with the iron forming an iron chloride film, an excellent EP lubricant.

Similarly, sulfur is added to sulfurize the mineral oil or fatty esters, including lard. In this case, the chemical reaction during the stamping results in an iron sulfide film.

Each additive has a temperature range, with a limit, where it is more effective. Some more severe stamping procedures require a combination of several lubricants to be more effective.

EP requirements, according to Klann (2000), for a variety of metals in the forming and stamping operations, can be completely different. For instance, while a simple drilling operation can be performed without chemical EP additives, the use of chlorine, phosphorus, or sulfur can significantly increase the tool life. The chemical film protects the punch mainly during the return, where the greatest amount of wear occurs due to the springback of the part.

Also according to Klann (2000), in stamping the high speed can generate a large amount of localized heat. An effective EP set, mechanical or chemical, is required not only to shape the piece without breaking it, but also to prevent "galling" and tool wear.

Often, parts are generated through severe stamping operations, then a combination of EP and limit lubrication are desirable. Besides ensuring that the most critical areas will receive the required lubrication, especially in multi-stage dies, in order to not threaten and inhibit the speed or tool life, and consequently the productivity.

4. EXPERIMENTAL METHOD

This work used commercial steel for stamping automotive structural parts, known in the industry as EP steels (buyer's name: FEP02). They were chosen for being the most used in industry today, regarding deep drawing plates. Table 1 shows the main mechanical properties of steels according to the EFF FG52806 standard.

Table 1. Mechanical Properties of FEP steels.

Denomination	Tensile Strength R (MPa)	Yield Strength	Minimum Elongation			Anisotropy r 90° min.	Hardening n 90° min.
			A_{80} (%)	A_5 (%)			
			Sheet Thickness (mm)				
			< 0.7	≥ 0.7			
FEP01	270 ÷ 410	140 ÷ 280	26	28			
FEP02	270 ÷ 370	140 ÷ 240	32	34		1,3	0,16
FEP04	270 ÷ 350	140 ÷ 210	36	38		1,6	0,18
FEP05	270 ÷ 330	140 ÷ 180	38	40		1,9	0,20
FEP06	270 ÷ 330	120 ÷ 180	40	42		2,1	0,22
			< 3,0		≥ 3,0		
FEP11	310 ÷ 430	210 ÷ 340	25		27		0,14
FEP12	270 ÷ 420	180 ÷ 330	27		32		0,16
FEP13	270 ÷ 410	170 ÷ 310	33		35		0,18

The specimen had quadrangular dimensions (200 x 200 mm) and an average thickness of 0.8 mm. After shaped piece takes the form of a cone as shown in Fig. 4.

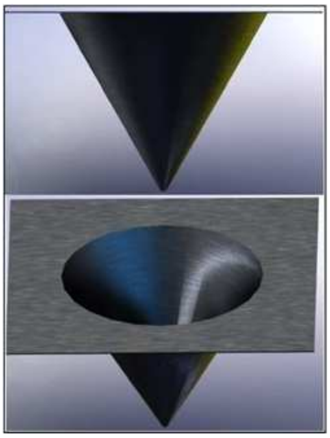

Figure 4. Geometry formed through incremental stamping on a modeled piece.

In order to employ incremental stamping, the ROMI Discovery 560 CNC machining center with Siemens Sinumerik 810D numerical control was used. The machine has 12.5 CV of power in a rotation range that varies from 10 to 10000 rpm. It was adopted a feed rate of 1500mm / min and spindle speed of 50 rpm. These values are within usage range of the process, data widely used in researches on the subject. The vertical increase was set as 0.5 mm/pass.

To measure the cone thickness a coordinate measuring machine (CMM) BR-M443 series MITUTOYO was used, where specified points of the cone were selected.

To perform the measurements it was used a roughness tester of the brand Taylor Hobson, where roughness measurements were made on both internal and external surfaces of all specimen, using parameters such as roughness Ra and Rq. These measurements were repeated three times at different points so that it would have reliable results.

Roughness Average (Ra) is termed as the arithmetic mean of the absolute values of the coordinates of departures from the roughness profile points, in relation to mean line within the measurement distance. The mean square roughness (Rq) is a parameter corresponding to Ra. It is the root-mean-square deviation. It is called RMS (Root Mean Squared) and gives notions of the magnitude of the roughness profile. Figure 5 shows how the roughness parameters were analyzed.

Figure 5. Roughness analysis done with profilometer.

5. DISCUSSION

Experiments were performed where the process of incremental stamping was applied on the specimen with variation on the piece-tool interface through the chosen lubrication, being done without any lubrication, with automotive wax polishing, graphite, MQF, and Petroleum jelly.

Measuring the internal average roughness (Ra) of the parts formed with different lubricants (Fig. 6), it can be noted that the largest surface roughness was found in the part that was used graphite as lubricant. This was possibly due to the lubricant behavior in front of the work piece-tool interface, since it was the only lubricant found in its solid state. The smallest value for roughness was found in the part conformed with Petroleum jelly. The MQF method (Minimal Quantity of Fluid) with a flow rate of 18 ml/h also showed a good solution for forming.

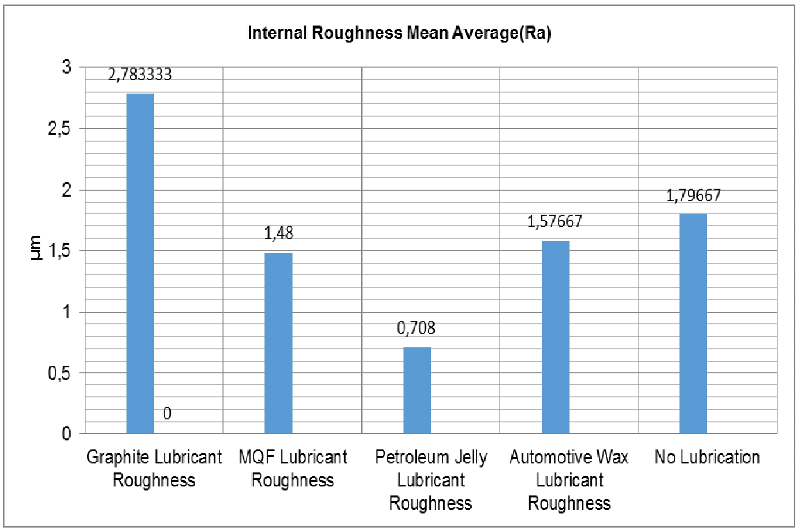

Figure 6. Roughness (Ra) of formed parts with different lubricants.

Analyzing the roughness parameter (Rq) of the inner surface of the part (Fig. 7) the same features seen in the Ra parameter (Fig. 6) can be noted, where you have Petroleum jelly with better finishing among the analyzed lubricants and the part formed with graphite with the worse. In this respect, it is seen that the piece-tool contact is highly influenced by the lubricant and, the more viscous it is, the better the internal characteristics are, therefore it cannot be solid. The graphite grains, upon making contact with the piece, created a third contact body, which contributed to the worsening of the finish. It is worth highlighting the high chemical affinity between the graphite lubricant and the steel, the material of both the part and the tool, which certainly contributed to the falling of this lubricant in tests.

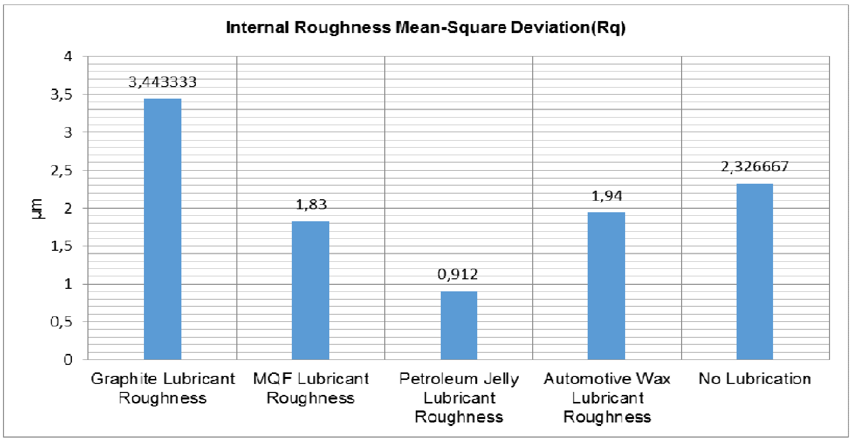

Figure 7. Roughness (Rq) of formed parts with different lubricants.

Evaluating the characteristics of the parts Fig. 8, made at a magnification of 30 times, it is noted that the piece with petroleum jelly is one that exhibits a better surface finish. The surface of the part formed without lubrication shows sharp lines of pass increments, which are not seen in the others. The worst finish is seen in part formed with graphite, due to the graphite grains facilitating friction by creating a third body. It is possible to highlight the impression that the tool leaves when performing the process without the use of lubricant or using automotive wax polishing.

Jeswiet and Hamilton (2010) investigated the effects of high spindle speeds and feed speed on the outside surface (no contact with the tool) roughness, where it commonly occurs the "orange peel" effect. The probable causes of the appearance of the orange peel, according to Hamilton, is due to different grain orientations on the surface. During the SPIF, these grains tend to stretch in different directions, which results in a rough surface.

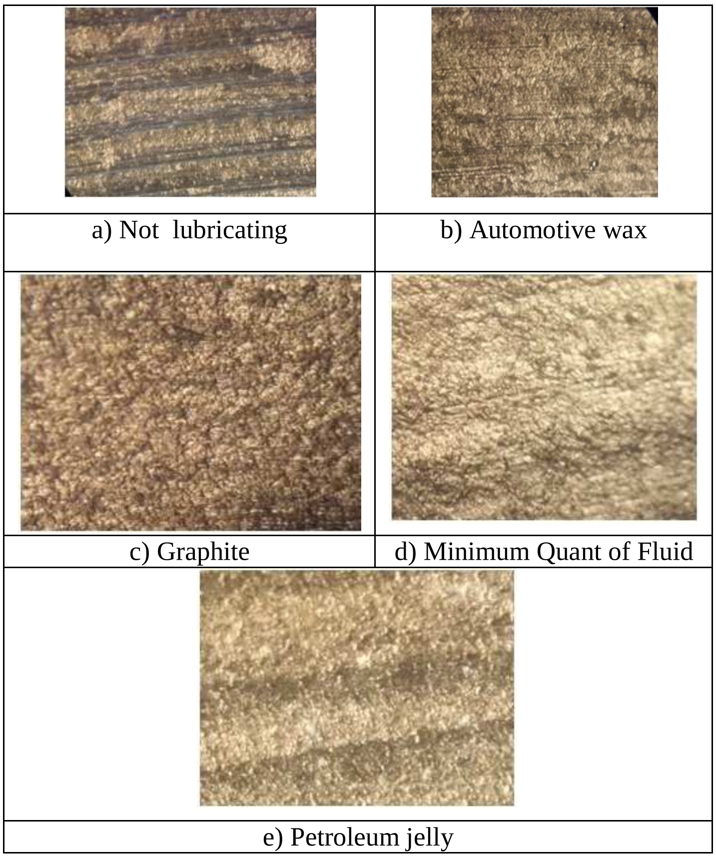

Figure 8. Characteristics of the surface formed parts.

6. CONCLUSION

The conclusion for this work is that the incremental stamping is highly dependent on the tribological pair created. It can be observed that the surface finish varied as the lubricant changed, with Petroleum jelly having the best results for both internal and external surfaces, which is explained by its viscosity and adhesion to the work piece-tool interface.

Vegetable oil applied through the MQF method was also interesting, obtaining promising finishing parameters, mainly by how the application of the fluid is done with this technique.

Promising results have been achieved with the use of powdered graphite as a lubricant. The implementation of a third body contributed to the worsening of the finish, generating a tribological pair of high chemical affinity (steel-graphite).

The piece formed with graphite kept virtually the same relation of the one formed without lubricant, indicating that the tensions distribution condition with this lubricant remained at close range.

7. ACKNOWLEDGEMENTS

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