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Effect of Different Lubricants on Deep Drawing of Galvanized Steel

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Abstract— Friction plays an important role in manufacturing processes.in some processes it is useful and required e.g. in rolling. However, in most processes it is harmful and not required as it causes wear of the tools and dies. Furthermore, it causes increase of the force and work required to perform the process which in turn will require higher machine capacity and special tools which adds to the manufacturing cost. In this paper, the effect of lubrication on the deep drawing process is investigated which includes: the effects on the force, energy requirements and the quality of the deep drawn cylindrical steel cups. The quality is assessed by the reduction in the amount of thinning, wrinkling, the height of ears and the bell shape. Five different lubricants were used and the obtained results are presented and discussed.

Index Terms— Effect, Different lubricants, Deep drawing, Maximum force, Consumed work, Deep drawing, Galvanized steel.

1 Introduction

DEEP drawing is one of the most widely used manufacturing process in metal working processes in general and in sheet metal forming in particular. It is considered a secondary forming process by which a sheet metal is formed into a cylindrical shape or alike. Historically, the process seems to be first utilized in 1939 when Swift published his first paper on the process. Since then metal forming researchers got engaged in investigating the parameters affecting the process in the cold condition. Different aspects of the process were dealt with trying to reduce or eliminate these defects and many papers were published on the subject which covers the subject from the study of the influence of parameters deep drawing to applications that can get new ways to optimize the process, [2-14]. Recently, the area of research in this field has extended to cover warm and hot conditions of deep drawing. Nowadays, considerable effort is being devoted to warm deep drawing due to its effectiveness in enhancing formability and because of its advantages such as manufacturing of complex shapes, improved formability, reduced production time and controlled plastic flow. Also attention has been directed towards super-plastic forming of sheet metal by deep drawing and blow forming, [15-20].

The process has been used to produce a very large variety of different geometrical shapes and sizes especially in the automobile and aircraft industries. For example, it is used for manufacturing a large number of the body and spare parts e.g. simple bend to double curvatures even with deep recesses and very complex shapes e.g. automobile bodies and aircraft panels of good strength and light weight i.e. high strength-to-weight ratio and corrosion resistible products. Also it is used in producing appliance bodies, kitchen utensils and beverage cans, the process is affected by many parameters which have great effect on the quality of the produced articles; those were reviewed and discussed in detail in Refs. [21, 22].

In its simplest form it may be defined as by subjecting the sheet to compressive force through a punch with a bottom end of the same geometry as the required shape of the cylinder bottom while it is placed on the upper surface of the die and held by the blank holder which hinders its movement but does not stop it.

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1.1 Friction and Lubrication in Deep Drawing

Friction is an important parameter in manufacturing processes, in some processes it is essential and required as in rolling but in the majority of processes especially in forming and material removal processes it is harmful because it causes wear of the dies and tools which in turn reduces their life time in addition it causes increase in the required force and work to perform the job, which in some cases needs machines of higher capacities and special tools which adds to the manufacturing costs. In such cases, lubrication is used to reduce or eliminate its harmful effects. Review of some of the published work on friction and lubrication in deep drawing is given and discussed.

The quality of deep drawing parts is influenced by certain variables that can be controlled. The flow of material during the deep drawing process depends on the type of lubricant used, which can affect the frictional forces between the active elements. Lubrication plays an important role in the drawing process, reducing the coefficient of friction thus having the role that contributes to the reduction of both the drawing force and the total work requirement to perform a certain job; in addition to the enhancement of the quality of the produced parts.

The evaluation of whether or not a sheet metal can be formed without defects depends on the material's properties, surface conditions, size and shape of the blank, lubrication, press speed, pressure applied by the punch and the die and punch design (Kuzman, 2000) and (Brown and Bosler Jr., 2006).

A good lubricant will also increase production rate and decrease failure rate. Most lubricants may be influenced by the tools temperature especially warm, hot drawing and in high energy rate drawing processes due to the adiabatic temperature rise. Furthermore, using lubrication requires cleaning the surface to get rid of any contamination before applying the

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lubricant. Furthermore, if the lubricants are not applied and disposed properly will form environmental problems for people especially the technicians during their application from the fumes and spoil the agricultural crop if it is mixed with irrigation water in their disposal; hence the lubrication process forms a pollution problem. Therefore, great care should be considered in choosing the lubricant type, method or system of application and disposal which may be costly and adds to the manufacturing cost.

In metal forming, especially in the deep drawing process, lubricants are used to reduce the friction between tool and workpiece. Thereby, the lubrication reduces forming energy and forming steps, increases the forming limit and tool life, while preventing galling, seizure and surface damages to the products. In addition, the disposal of a large amount of lubricant waste is a serious environmental and economic issue. Furthermore, using any lubricant in metal forming processes requires cleaning of the forming parts, usually several times between subsequent production steps in multi stage-forming as redrawing processes. Therefore, various green manufacturing strategies under laboratory conditions have been developed by manufacturer.

To avoid the lubricants harmful implications, a novel method was suggested and presented in Ref. [37] for free drawing without use of lubricants by controlling the important variables and by means of a new macro structured tool design, claiming that the new tool structure enables the control of friction forces as well as the material flow. The basic process principles and an analytical model for the process design supported by the experimental results for symmetrical geometries which will be applied to three dimensional complex parts are presented in the paper. To avoid the pollution problems to the environment pollution problems an environmental friendly lubricant was suggested in Ref. [35].

The literature on friction and lubrication on stretch forming is voluminous and some of the references are given in Refs. [26-37].

2 Materials, Equipment and Experimental Procedures

2.1 Materials

The specimens were circular discs of 180 mm diameter and 0.42mm thickness made from galvanized steel of the mechanical behavior shown in Fig.1.

The main deep drawing die and all the other punches and dies which were used for investigating the different parameters in this paper were all made of the same material, X12M and heat treated in accordance with the heat treatment cycle recommended by the suppliers. The obtained hardness was RC65. Their chemical composition, X12M, is shown in Table 1.

Five punches and five dies with different diameters and different profile radii were machined and ground under the same cutting conditions. Their diameters were measured using the Tool Makers travelling microscope and their profile radii were determined using the shadow graph at a magnification X20. The values of the radial clearance percentages for the different combined punches and dies are shown in Table 2.

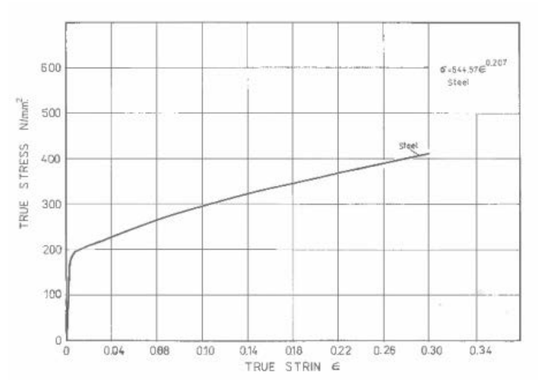

Fig. 1. True stress-true strain of the work piece material

TABLE 1
CHEMICAL COMPOSITION OF X12M

Element	Wt. %
C%	1.70%
Mn%	0.35
Si%	0.4
Cr%	0.12
V%	0.3
Fe%	Bal.

TABLE 2
THE VALUES OF RADIAL CLEARANCE AND RADIAL CLEARANCE PERCENTAGES

Symbol	Radial clearance mm	Radial Clearance %
C1	0.3976	94.8
C2	0.4473	106.6
C3	0.4943	117.8
C4	0.545	129.9
C5	0.5695	135.7
C6	0.7947	189.4

TABLE 3
VALUES OF PUNCH PROFILE RADII

Symbol	Punch profile radius (mm)	Rpn/pr
rp1	2	3.34
rp2	5	8.34
rp3	10	16.67
rp4	15	20
rp5	20	33.34

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The values of the punch and die profile radii an are shown in Tables 3 and 4respectivly.

TABLE 4
VALUES OF DIE PROFILE RADII

Symbol	Die profile radius (mm)	Rdn/dr
rd1	2	4.77
rd2	4	9.53
rd3	6	14.3
rd4	10	23.84
rd5	15	35.75

2.2 Equipment and Experimental procedures

For papers accepted for publication, it is essential that the The deep drawing tests were carried out using the deep drawing die shown in Fig.2 which was designed and manufactured for this purpose. It consists of the following main parts: the upper and lower platens which are concentric and held in line together, the sleeves the blank and die holders were all made of galvanized steel.

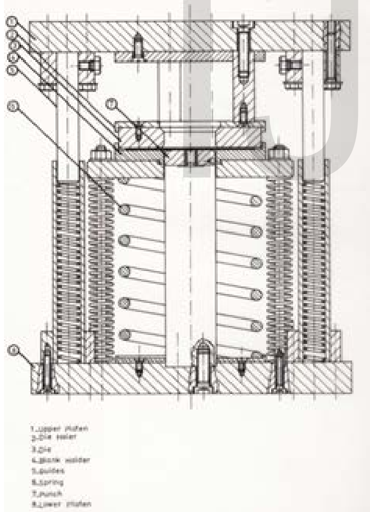


Fig. 2. Schematic drawing of the deep drawing die

3 RESULTS AND DISCUSSION

In this section, the effect of the addition of the five different lubricants on the thickness strain distribution, the relation between punch and die profile radii, maximum drawing force, the total consumed work and the defects encountered in the process are presented and discussed.

3.1 Effect of Lubrication on the Autographic Records

Examination of all the autographic records which were produced with the different lubricants and with the different punches and dies combinations revealed that a very slight or no difference existed among them and even with the dry condition as illustrated in Fig. 3 which gives comparison between the lubricated and dry test for the combination of P2 with D1. This is unlike the case of the different combinations of punches and dies in the dry condition where some pronounced difference existed and some failure has occurred for some cups, whereas no failures have occurred in the lubricated conditions because failure is mainly caused by maximum thinning when it exceeds certain limits and thinning is very small in the lubricated condition as compared to the dried condition and better quality of produced cups as will be discussed in the following section.

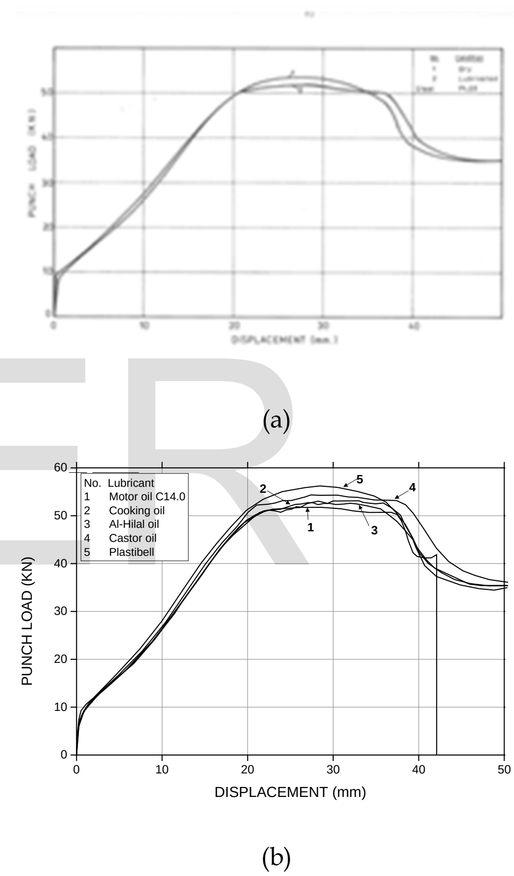
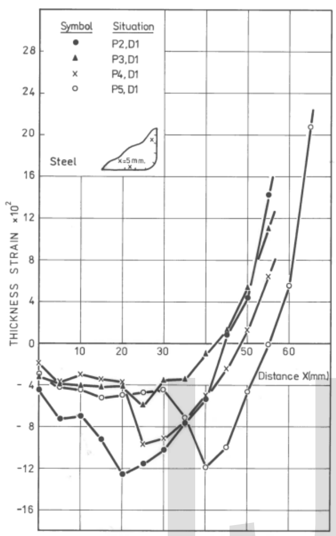


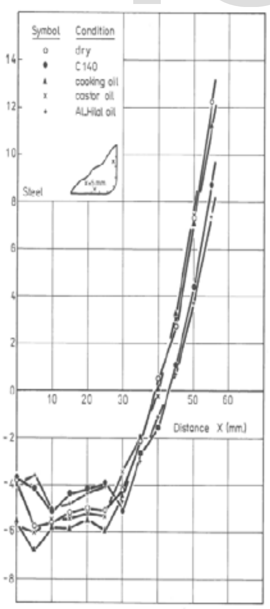
Fig. 3. Effect of lubrication on the autographic records, (a) for the dry condition and lubricated for the combination of P4 with D3 and(b) for the four lubricants and the dry condition

3.2 Effect of the Different Lubricants on the Thickness Strain Distributio

The effect of lubrication on the thickness strain distribution is demonstrated in Fig. 4. Also the dry condition is included for comparison purposes. It can be seen from this figure that the general trend is identical where very little thinning has taken place at the base of the produced cup. Its value ranged between 4 and 6.8%. This is attributed to stretching at the punch radius. Furthermore, it can also be seen that thickening has occurred at the upper wall of the cups, (with little or no difference among the different lubricants) in the region of the blank which was originally located between the upper surface of the die and the blank holder before the starting of the drawing process. This thickening is attributed to the induced compressive stresses. The maximum thinning which has occurred in the dry condition is much higher than that in the lubricated condition as can be seen from Fig. 4 (a) for the same combination of P2 with D1. The maximum amount of thinning in the dry condition is 12.15% as compared to 6.8% in the lubricated condition. This indicates that the lubricants have reduced the liability of necking and crack initiation. Similarly, the lubricants have reduced wrinkling and the height of ears.



(a)



(b)

Fig. 4. Effect of punch profile on thickness strain distribution (a) for combinations of P2, P3, P4 and with D1 without lubrication and (b) is the effect of the four used lubricants and the dry condition on the thickness strain distribution

3.3 Effect of Lubrication on the Relation between Die Profile and Punch Profile Radii, (Design Curve)

The relation between die profile and punch profile radii defines the punch and die profile radii which produces successful cups as illustrated by Fig. 5. It can be seen from this figure that values which fall above the dotted line always produce failure of cups, whereas the combinations of punches and dies falling below the continuous line always produce successful cups. The points which fall between the two lines produce sometimes successful cups and sometimes failure of the cups.

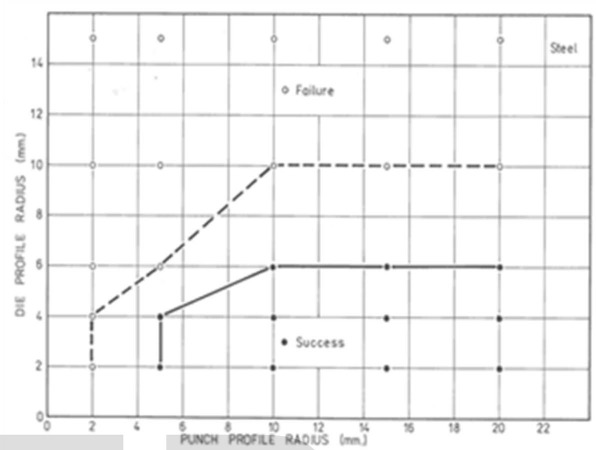


Fig. 5. Die profile versus punch profile radius, (design curve)

3.4 Effect of Lubrication on the Maximum Drawing Force

Examination of Fig. 6 shows the effect of the four different used lubricants namely: Motor oil C140, Cooking vegetable oil, (sun flower), Recommended deep drawing oil from Al-Hilal and Castrol oil as compared to the dry condition. It can be seen from this figure that all the lubricants resulted in reduction of the maximum drawing force by different percentages as illustrated in Table 5.

TABLE 5
EFFECT OF THE DIFFERENT LUBRICANTS ON THE MAXIMUM DEEP DRAWING FORCE

Condition	Maximum drawing force (KN)	Reduction Percentage
Dry,(no lubricants)	57	
Motor oil C140	52	8.78
Vegetable cooking oil	52.5	7.89
Special recommended deep drawing oil Al-Hilal	53	7.02
Castrol oil	53.9	5.44

It can be concluded from this Table that the most effective lubricant is Motor oil C140 and the least effective is Castrol oil. It was also observed that all the lubricants showed lower thinning and more uniformity in thickness strain distribution than the case of dry condition.

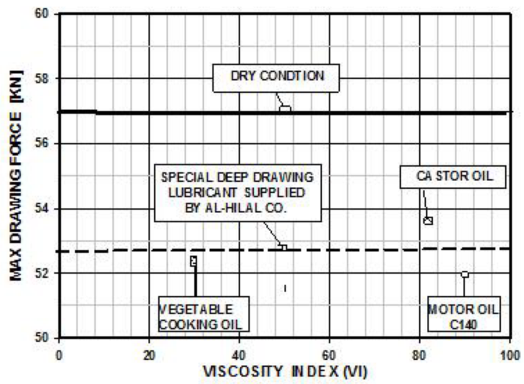


Fig. 6. effect of the different lubricants on the maximum drawing force

3.5 Effect of Lubrication on the Total Consumed Work

The effect of the four used lubricants on the total consumed work by the galvanized steel cups is represented in Fig. 7. Also the work consumed by the cup in the dry condition is shown in the figure for comparison purposes. It can be seen from this figure and the results in Table 6 that the four lubricants have reduced the total consumed work with the following reduction percentages: 5.1, 4.7, 3.96 and 1.98 Motor oil C140, Vegetable cooking oil (sun flower), Special recommended deep drawing oil supplied by Al-Hilal co. and Castrol oil respectively.

TABLE 6
EFFECT OF THE DIFFERENT LUBRICANTS ON THE TOTAL CONSUMED WORK

Condition	Total consumed work, (Joul)	Reduction percentage
Dry, (no lubricant)	20.2	
Motor oil C140	19.17	5.1
Vegetable cooking oil	19.25	4.7
Special recommended deep drawing oil Al-Hilal	19.43	3.96
Castrol oil	19.8	1.98

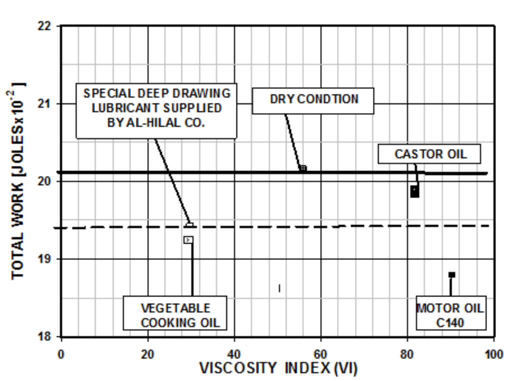


Fig. 7. Effect of the different lubricants on the total consumed work

4 CONCLUSION

Within the experimental limitations, the following points are concluded:

(A). In the dry condition:

i). The punch and die profile radii, Rp and Rd, has pronounced effect on the autographic records being more influenced by the die profile radius.

ii). The maximum amount of thinning is affected by both the punch and die profile radii being more influenced by the die profile radius as the material over it is subjected to bending and stretching while the material over the punch profile is subjected to stretching, even though the necks which lead to cracks and fracture are in the contiguous region to the punch profile radius.

iii). The maximum drawing force decreases with increase of the die profile radius, Rd, whereas its liability for wrinkling and bell shaped cups increases. The optimum value for the used steel was found at Rd = 6 mm which equals about 15 times the original sheet thickness; whereas it increases with the increase of the punch profile radius, Rp up to a limit when Rp = 15mm it starts to decrease. In general, the maximum drawing force is less affected by the punch profile radius.

iv). The total consumed work in drawing the galvanized cups was also affected by the die profile radius; it decreases with the increase of Rd and is slightly influenced by the punch profile radius Rp with a maximum value of 6%.

(B). In the lubricated condition:

i). The punch and die profile radii have very little or practically no effect on the autographic records for all the lubricants and punches and die combinations.

ii). All the lubricants have resulted in reduction of the maximum drawing force for all combinations of punches and dies. The percentage reduction depends on the type of used lubricant. The following reduction percentages in the drawing force for the used lubricants are as follows: Motor oil C140 8.78, vegetable cooking oil, sun flower: 7.89, Special recommended deep drawing oil: 7.02 and Castrol oil: 5.44

It can be seen from the above results that motor oil C140 is the most effective lubricant followed by the cooking vegetable oil,(sun flower) then by Al-Hilal oil and the least effective is the castor oil.

iii). All the lubricants have resulted in reduction of the total consumed work by the following reduction percentages: Motor oil C140 5.1, vegetable cooking oil, sun flower: 4.7, Special recommended deep drawing oil: 3.96 and Castrol oil: 1.98.

It can be seen that their relative effectiveness in reduction of the total consumed work is the same sequence as the reduction in the maximum force but with less values.

iv). Despite the voluminous amount of publications over the last seven decades, the parameters involved in the deep drawing process are far from being optimized and more research work needs to be carried out to render the process free from defects and cost effective.

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