International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Investigation on formability of Aluminium 6061 alloy Sheet under various forming conditions through Erichsen Cupping Test machine

Bhav Gautam†*, Vaibhav Chandra†, Praveen Kumar†, Narayan Agrawal† and Sunny Kumar†

†Department of Tool Engineering, Delhi Institute of Tool Engineering, Okhla, New Delhi, India

Accepted 30 Dec 2015, Available online 02 Jan 2016, **Vol.6, No.1 (Feb 2016)**

Abstract

In forming aluminium 6061alloy sheet, heat generated, due to friction between die and sheet, is greatly reduced by the application of lubricants. In this study, a comparison has been done between lubricant coated and uncoated (unlubricated) aluminium AA6061-T6 alloy sheet using Erichsen Cupping Test. For uncoated sheets, test was done under dry and heated conditions whereas for lubricant coated sheets, effectiveness of three lubricants (boric acid, graphite and Teflon or PTFE) was examined. The performance of lubricants was based on two parameters i.e.Draw Force and Draw Depth. The results of lubricant coated and uncoated AA606-T6 sheets were compared to determine the optimum performance of lubricants used. It was found that sheet under uncoated heated condition required minimum draw force whereas maximum was found in uncoated dry condition. The draw force for lubricant coated sheets was between dry uncoated and heated conditions. Also, the application of lubricants showed more draw depth when compared with uncoated conditions. This study concluded that the application of boric acid as lubricant onAA6061-T6 alloy sheets had optimum performance when compared with other lubricants.

Keywords: *Erichsen Cupping Test, Solid lubricants, Draw force, Draw depth, formability,AA6061-T6 alloy sheet.*

1. Introduction

A wide range of consumer and industrial products, such as metal desks, appliances, beverage cans, car bodies, and kitchen utensils, are now being produced using sheet metal forming operations. Sheet metal forming, also called as press working, press forming or stamping, is amongst the most ancient and important metalworking process. Sheet metal parts offer the advantages of light weight and shape versatility, over those made by casting or forging. Unlike bulk deformation processes, sheet forming, involves work pieces with a high ratio of surface area to thickness. A sheet thicker than 6 mm is generally called plate.

Formability is defined as the ability of the material (metals) to be deformed into desired shape, on applying mechanical force on it. Generally, forming of sheets metals is carried out by tensile force in the plane of the sheet, or else the application of external compressive force could lead to buckling, folding or wrinkling of the sheet. The success or failure of the formed sheet metal components depends on the material flow properties, ductility, die geometry, die materials, lubrication conditions and press speed.

1.1 Need for formability Tests

The major reason for formability of sheet metals has been of great and continued interests is due to its technological as well as economic significance. Sheet metal formability is generally defined as the ability of a sheet to undergo the desired shape change without any failure such as necking, tearing, or splitting.

In recent times, a lot of importance is given to the kind of lubricants used worldwide, in order to check the various health and environmental hazards caused by certain toxic lubricants. Moreover, lubricants are often flammable and thus possess great risk. It is also found that some very common lubricants contain active elements such as chlorine, sulphur, and phosphorous, which are potentially hazardous.

1.2 Factors influencing the formability

Three factors have a major influence on formability:

a) Properties of sheet metal, like yield point elongation, anisotropy, grain size, residual stresses, springback, wrinkling, coated sheet.
b) Friction and lubrication at various interfaces in the operation
c) Characteristics of the equipment, tools, and dies used

1.3 Various cupping tests used in sheet metal industries

The following are the cupping tests used for measuring the formability of sheet metals:

*Corresponding author: **Bhav Gautam**

a) Erichsen test (stretching)
b) Olsen test (stretching)
c) Swift cupping test (drawing)
d) Fukui test (drawing)
e) Nakajima test (stretching)

Such cupping tests measure the capability of the material to be stretched before fracturing and are relatively easy to perform.

Apart from iron, aluminium is currently the next most widely used metal in the world. This is due to the fact that aluminium has a unique combination of attractive properties. Properties such as its low weight, corrosion resistance, and easy maintenance of final product, have ensured that this metal and its alloys will be in use for a very long time. Aluminium 6061 alloy is a wrought alloy.

2. Literature Review

In stamping industry, lubrication plays an important role as it reduces friction between tool and workpiece interface. Different types of lubricants show different characteristics. This difference is especially noticeable when comparing liquid and dry-film lubricants. As dry-film lubricants do not run off the blanks' surface and are distributed homogeneously, they show different tribology properties compared to conventional liquid lubricants (Meiler and Jaschke, 2005). Evaluation of five stamping lubricants (four dry lubricant and one wet lube) was done using practical methodology that uses deep drawing test and finite element (FE) analysis (Kim and Altan, 2005).The performance of lubricants were based on six parameters, namely, i) Maximum punch force, ii) blank holder force, iii) draw-in-length, iv) perimeter of flange, v) surface roughness and vi) surface tropology.

The methodology used was both effective and accurate to determine the performance of the stamping lubricants. The Erichsen cupping test is used in this investigation as a ductility test, which is employed to evaluate the ability of metallic sheets and strips to undergo plastic deformation in stretch forming (Hawtin *et al*., 1963).

Various stamping lubricants were tested in forming of advanced high strength steels (AHSS) DP590 GA round cup samples (Kim, *et al*. 2008). The effectiveness of stamping lubricants was evaluated by using the deep drawing and ironing tests. It was concluded that Polymer-based thin film lubricants with pressure additives were more effective than other lubricants on the basis of punch force and geometry indicators. In another research on deep drawing it was concluded that for three aluminum alloys (1100, 5052 and 6111), the lubricity of boric acid film was comparable with that of commonly used commercial lubricants, and its lubricity was good over a widerange of forming speeds(K.P. Rao, *et al*, 2001). Moreover, SEM photographs indicated noscratches on the deformed surfaces under boric acid lubrication. In a review paper, aluminum and steel formability was analyzed (Story, *et al*, 1993). The adverse effect of poor lubrication develops direct contact between workpiece and tool. This leads to accumulation of softer workpiece material to tool surface. This build-up of particles on the tool, i.e. galling, is particularly significant in the forming of aluminum alloys.

As a result, this leads to deformation in tool geometry and increase in forming force. Use of complex polymeric esters to replace chlorinated additives, fatty acid soaps and sulfurized materials as metal working fluids have also been discussed (Miller, *et al*. 1997). The study compared its cost, performance and environmental advantages. Balulescu, *et al*, found that neat or water-soluble derivatives of vegetable oils show very good performances in cutting operations, equaling or even surpassing the performance of conventional additives (Balulescu, *et al*. 1994).The interactions between lubricants and zinc coatings on steel sheets using a drawbead simulation tester were studied (Schey, *et al*. 1998). The results indicated that oleic acid can destroy the stability of the zinc transfer layer when sheets have a significant basal component (Zn) in the coating, resulting in junction growth, plowing and high friction, although it reduces friction on bare steel. However, a boron compound with 7.6%B seems to prevent junction growth and keep friction low (Branneen, *et al*. 1990). In addition, some works indicated that boric acid could be used as a good additive in cutting and grinding fluids to control friction and corrosion (Rekow, *et al*. 1993). Liang *et al*, found that addition of boric acid into distilled water increases the drilling rate of polycrystalline alumina (Liang, *et al*. 1995). The works of Erdemir, Fenske and Wei found that boric acid appears to be firmly adhered to aluminum surfaces and provides very low friction coefficient (about 0.04). Boric acid dry film alone and in combination with mineral oil can yield strains larger than commercial liquid and solid lubricants in a out-of-plane stretching test, indicating that they could be very good lubricants for aluminum cold forming. The lubricity of boric acid is related to its layered structure, in which the bonds between the layers are much weaker than interlayer bonding (Erdemir, *et al*. 1998).

3. Experimental Details

3.1 Testing Equipment

The cupping test was carried out on a machine equipped with a die, punch and blank holder with dimensions and tolerances as shown in fig. 1 and fig. 2.

The machine was equipped with a gauge (plunger type comparator) for measuring the movement of the punch with a least count of 0.01 mm. The distance from the axis of the die to the Centre of the spherical part of the punch is less than 0.1 mm throughout its range of movement. To ensure the holding of the test piece, a constant holding force of 10 kN was applied.

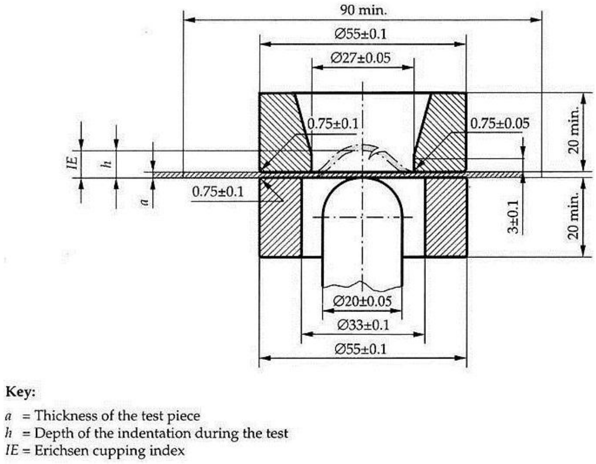

Fig.1 Illustration of the Erichsen cupping test machine

Fig.2 Erichsen cupping test machine.

3.2 Materials and Lubrication used

Fig.3 shows the summary of the test conditions for this study.

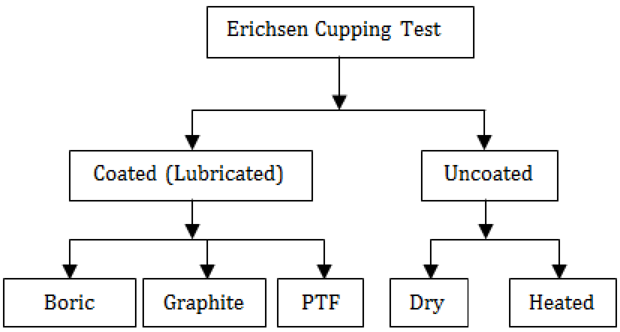

Fig. 3 Flow chart depicting the formability conditions used in this study

In this study, single aluminum alloy sheet of AA6061-T6 was used to compare the effectiveness of various lubricants with uncoated condition through Erichsen cupping test. The chemical composition of the aluminum 6061 alloy is given in Table 1 (K.P. Rao, *et al*, 2001).

Table 1 Typical compositions of the aluminum 6061 alloy

Trade code	Grade	Composition (wt.%)				
		Mg	Si + Fe	Mn	Cu	Cr
6061	T6	1.0	0.4-0.8	0.15	0.30	0.2

Thickness of the test specimen was 2.0 mm, length and width being 180mm and 90mm. The blanks were washed with commonly used dishwashing detergent and dried in air, before coating with lubricants.

Since the solubility of boric acid is significantly higher in ethanol than in water. Thus, solution of boric acid with ethanol was prepared by stirring them at room temperature.

The solution was brushed on both sides of the cleaned aluminum sheets. Dry films were obtained within a couple of minutes after evaporation of ethanol. The brushing process was repeated two more times so as to build a sufficiently thick layer of lubricant film. The other selected lubricants were Graphite and Teflon or PTFE (polytetrafluroethylene).

Moreover, the results obtained were also compared with aluminum 6061 alloy sheet in normal and heated condition. The sheet was heated using electric oven up to a temperature of 150°C as shown in fig.4.

3.3 Test procedure

Fig. 4shows the oven used for heating the aluminum 6061 alloy sheet

Erichsen cupping test machine was used to analyze the effect of various lubricants on the draw depth and draw force. Fig.5.aand5.b shows the image of test piece before and after fracture in Erichsen cupping test.

Fig. 5.a shows the hemispherical cup (before fracture)

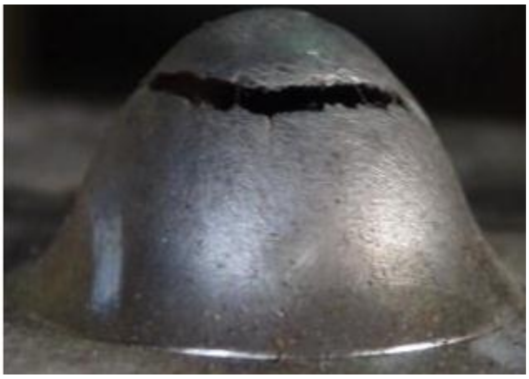

Fig. 5.b shows the crack in sheet (after fracture)

In the drawing process, the sheet metal is drawn into a die cavity with use of a circular punch. Sheet metal blank is held in place by a blankholder ring, and then the punch moves up to a preset stroke. For ideal deep drawing, it is required that the workpiece be drawn into the gap between punch and die to form a cup-shape part without over-all thinning. However, in dry condition (unlubricated) or under insufficient lubrication, thinning and fracture of sheets may occur. The diameter of the punch (D) is 20 mm. The size of the blank, used for the experiment was 180x90x2 mm.

4. Results and Discussions

4.1 Application of lubricants

Table 3 shows the amounts of lubricants employed in this study, which were established after some trials. It may be noted that the least amount of lubricant used in the case of boric acid followed by PTFE.

Table 3 Amount of lubricants applied to sheet materials

Lubricant	Amount of lubricant (gm/m^{2})
Boric acid	8.3-9.8
Graphite	83.5-95.2
Teflon or PTFE	10.6-12.3

Fig. 6 shows the comparison of amount of various lubricants applied in gm/m^2 (using average values given in table 3).

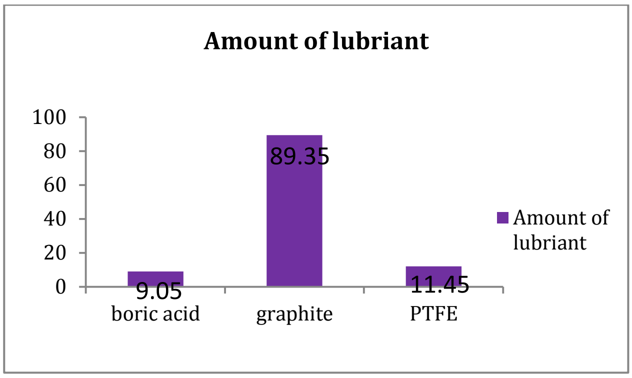

Fig. 6 Amount of lubricants applied on aluminum 6061 alloy sheet (in gm/m^2)

4.2 Draw Force

Fig. 7 shows the maximum draw force obtained in dry (uncoated) condition whereas minimum draw force was obtained in heated condition. It was also observed that draw force for coated (lubricated) sheets lie between the dry and heated condition. This was expected as in uncoated condition, large amount energy is dissipated in the form of heat because of friction between die and sheet, thus draw force also increased. Due to increase in plastic behavior (in metals) at high temperature, minimum draw force was observed under heated condition.

The effect of lubricant enhanced the flow of sheet during its forming. It was observed that application of boric acid and ethanol solution showed minimum draw force, followed by graphite solution, in comparison with other lubricated sheets. This showed that the solution of boric acid was most effective in reducing the friction between workpiece and die.

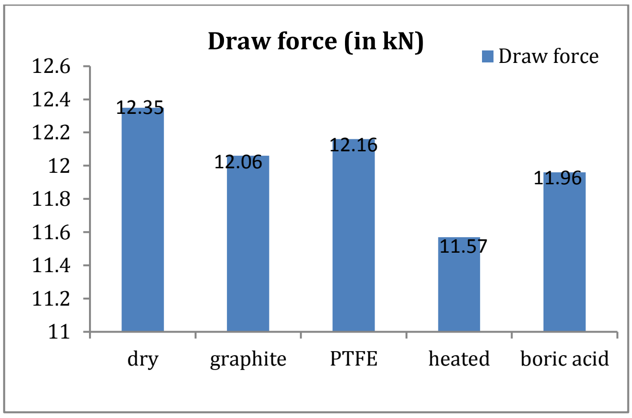

Fig. 7 Maximum draw force obtained for aluminum 6061 alloy sheet under various lubrication conditions.

4.3 Draw Depth

Fig. 8 shows the draw depth obtained in various conditions before fracture of sheet. The maximum draw depth was obtained for PTFE and boric acid solution coating condition, followed by graphite solution coating. It was observed that minimum draw depth was obtained by uncoated condition, preceded by heated condition. This shows the advantage of application of lubricants over dry and heated condition.

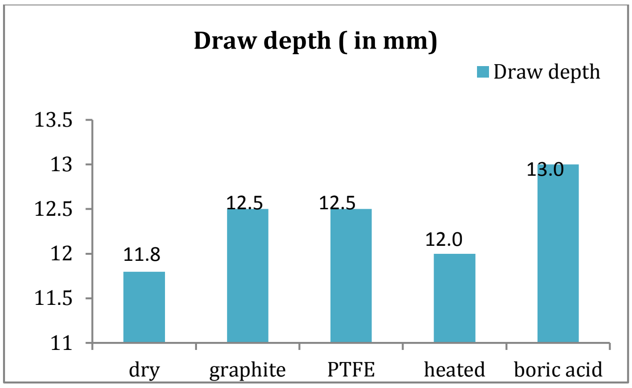

Fig. 8 Maximum draw depths for aluminum 6061 alloy sheet under various lubrication conditions

Fig. 9 shows the CAD model for the aluminum 6061 alloy sheets after Erichsen cupping test. This figure shows the draw depth of sheet, before fracture, under coated and uncoated conditions. Maximum draw depth for boric acid condition is shown by V. Whereas II and III shows equal draw depth in graphite and PTFE conditions. Draw depth in uncoated conditions i.e. heated and dry, are shown by IV and I, respectively.

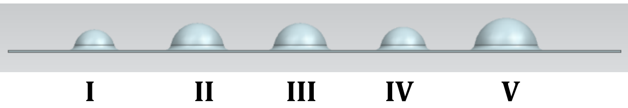

Fig. 9 Front View of aluminum 6061 alloy sheet under various lubricants (after Erichsen cupping Test)

Conclusions

The lubrication effectiveness of boric acid films for formingAA6061-T6 sheet was investigated using Erichsen cupping test under room temperature. The effect of lubricant was compared with sheets in normal and heated (i.e. unlubricated) conditions under the same operation. Based on the above tests, the following conclusions can be drawn:

1) The Erichsen cupping test indicates that, for aluminum 6061 alloy sheet, the lubricity of boric acid, followed by PTFE, is comparable to the sheet in heated condition. According to fig. 7, draw force for boric acid is just 3.37% more than that in heated condition whereas when compared for dry condition, draw force is 6.74% more.
2) The effect of other lubricants i.e. graphite and PTFE, also reduces the drawing force up to an extent, when compared with uncoated heated sheets
3) On considering the maximum draw depth, under various lubrication conditions, it can be concluded that here also sheet coated with boric acid and PTFE shows maximum draw depth. From fig. 8, the draw depth in boric acid condition is 8.33% more than that in uncoated heated condition.
4) Fig. 6 shows that the amount of boric acid applied on aluminum 6061 alloy sheet was almost 90% and 21% less than the amount of graphite and PTFE, respectively.
5) Thus, desirable results were obtained when boric acid was used as a lubricant in drawing operation.
6) The use of boric acid as lubricant is emphasized as it is less toxic and water soluble. Thus, post-cleaning of the formed components will be easier.

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