

# Lubrication study for Single Point Incremental Forming of Copper

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**Abstract.** In conventional machining and sheet metal forming processes, in general, lubrication assists to increase the quality of the final product. Similarly it is observed that there is a positive effect of the use of lubrication in Single point incremental forming, namely in the surface roughness. This study is focused on the investigation of the most appropriate lubricant for incremental forming of copper sheet. The study involves the selection of the best lubricant from a range of several lubricants that provides the best surface finishing. The influence of the lubrication on other parameters such as the maximum forming angle, the fracture strains and the deformed profile are also studied for Copper.

## 1. Introduction

Recent studies have shown the application of single point incremental forming (SPIF) in medical [1] and industrial field [2]. Despite the fact that the SPIF lead time is high when compared with conventional sheet metal forming, its application for prototyping and job production can be justified. In this process the sheet metal blank is clamped firmly on the rig, the blank is then formed incrementally by a SPIF tool controlled by CNC. SPIF uses an universal tool i.e. a ball or hemispherical ended tool eliminating the need for the customised die used in conventional sheet metal forming. Lubrication has been primarily used in SPIF to reduce tool wear [3,4] and recently used in order improve the surface finish [5].

It is interesting to note that even though some studies [3,5] have shown that the surface finish improves when lubrication is used, other [6] shows negative effect of lubrication on formability. Thus it is important that the effect of lubrication on formability of the material should be studied. In this study formability is assessed on the basis of maximum forming angle, fracture strains and deformed geometry.

## 2. Material and Methodology

### 2.1 Material

The material used for this study is Copper. Copper finds a wide application in sheet metal industry in particular in the home appliances industry. Copper has a relative good ductility. Although for direct comparison of all the lubricants no spring-back compensation strategies were used in the experimental work. The material properties are presented in table 1. The preparation of the blanks involved electrochemically etching of grid with circles of 2.5mm diameter in order to evaluate the strains. It can be observed from table 1 that the material anisotropy is almost 1.

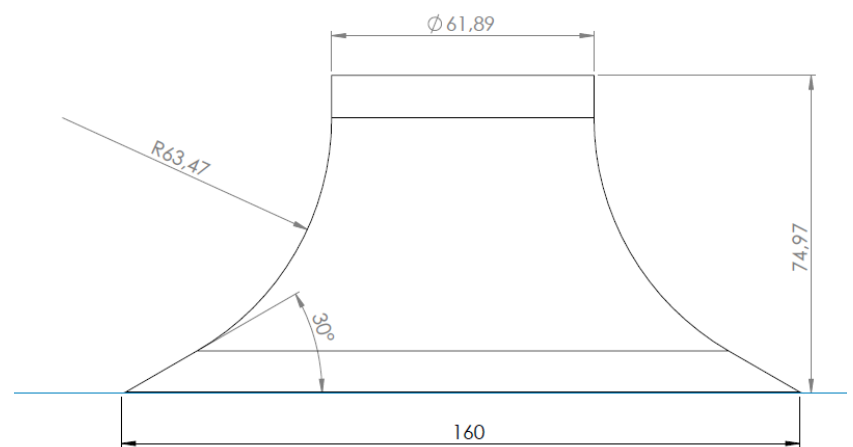


## 2.2 SPIF tool and machine.

A 5 axis CNC machining centre and ball ended forming tool with 12 mm of diameter were used to carry out the experiments. The blank was firmly clamped on the rig as shown in figure 1. The geometry selected for the SPIF test was the benchmark truncated conical geometry, as shown in figure 1, which starts with constant angle of 30° and later increases constantly.

**Table 1:** Material properties of Copper

Engineering stress (MPa)		True stress (MPa)		A [%]	Young's Modulus E (MPa)	Normal anisotropy
$\sigma_Y$	$\sigma_{UTS}$	$\sigma_Y$	$\sigma_{UTS}$			
208.1	261.7	208.9	331.3	26.7	114343.8	0.98



**Figure 1:** a) Experimental setup

b) Truncated conical geometry (dimension in mm)

## 2.3 Lubrication

The process parameters and the tool path were kept the same throughout the experimental work. Six lubrication conditions were used as presented in table 2. For each lubrication condition two specimen were produced.

**Table 2:** List of Lubrication used

Lubrication condition	Lubricant reference	Chemical composition	Base	State	Viscosity (mm/s <sup>2</sup> ) at 40°C
1	Copaslip	15% hydrated Mg silicate + 15% Copper flakes + 15% hydrocarbon polymer	Mineral oil	Paste	96.2
2	AS40	40% MoS <sub>2</sub> + 15% graphite powder + 25% EP lithium grease	Petroleum oil	Paste	na
3	Weicon Ni Special	20% Ni powder + 10% Calciumhydroxide	Mineral oil	Paste	na
4	Weicon montage	20% ceramic powder + 10% Aluminiumpulver	Mineral oil	Paste	185
5	Castrol Magnaglide D68	Mineral oil	na	Oil	68
6	no Lubrication	na	na	Na	na

### 3. Results

#### 3.1 Surface Roughness

Table 3 presents the average surface roughness obtained in the experimental tests. It was observed that all lubrication conditions reduced surface roughness. Lubrication conditions 3 and 5 provided an optimum surface roughness although when compared, lubrication condition 5 is more economical. It is also observed that lubrication state 2 is highly not recommended as it results in stains on the finished part. Stains might be a result of the reaction of  $\text{MoS}_2$  with copper [7].

**Table 3:** Effect of lubrication on Surface roughness

Lubrication condition	Quantity of Lubrication (gm)	Ra ( $\mu\text{m}$ )
1	25.81	0.6950
2	31.93	0.5667
3	37.69	0.4216
4	45.06	0.4350
5	18.96	0.3933
6	-	0.7200

#### 3.2 Strain analysis

The true fracture strains were calculated using circle grid analysis and the results obtained are presented in table 4. As the conical geometry results to in-plane strains; only major strains are used for analysis. It can be inferred from the observation that there is no significant effect of lubrication on the resultant fracture strains.

#### 3.3 Maximum forming angle

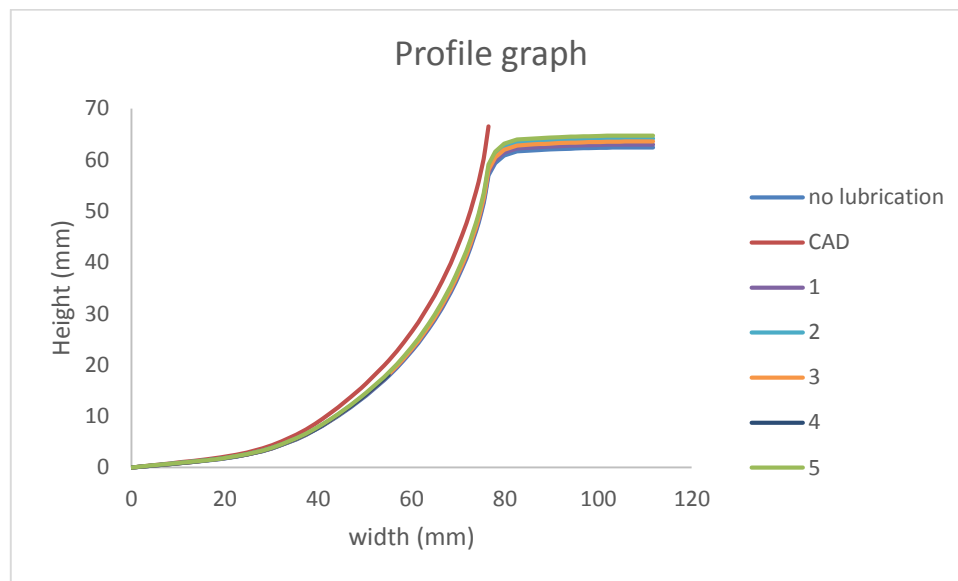
The maximum forming angle was calculated based on the depth at which the fracture occurred and comparing the equivalent angle for the same depth in the CAD geometry. Here, as can be seen in table 4, there is no significant effect of lubrication on the maximum forming angle. However quantitatively, it can be stated that the lubrication has negligible positive effect on the maximum forming angle.

**Table 4:** Fracture strains and maximum forming angle

Lubrication state	Average fracture strain	Maximum forming angle ( $\psi$ in deg)
1	1.34	76.08
2	1.34	76.46
3	1.35	76.85
4	1.34	76.35
5	1.35	77.38
6	1.34	75.99

#### 3.4 Profile deviation

As the geometry formed in this study is axi-symmetrical and anisotropy is negligible, it was analysed only one profile along the depth of the final geometry. Here it was observed that there was no significant effect of lubrication on all the profiles. Figure 2, presents the theoretical geometry from CAD and the experimental profiles obtained from several lubrication conditions. It can be stated that the formed geometries are significantly deviated from the CAD geometry due to spring-back effect.



**Figure 2:** Profile deviation

#### 4. Conclusion

From this study it can be concluded that the mineral oil based lubricants are economical and an optimum choice for incremental forming of Copper, having a significant and positive effect on surface finish. It can also be concluded that the lubrication conditions, in the case of Copper, do not affect the formability.

#### 5. Acknowledgement

Author(s) gratefully acknowledge the funding of SciTech - Science and Technology for Competitive and Sustainable Industries, R&D project cofinanced by Programa Operacional Regional do Norte ("NORTE2020"), through Fundo Europeu de Desenvolvimento Regional (FEDER) and *Fundação para a Ciência e a Tecnologia of Portugal* and LAETA – UID/EMS/50022/2013.

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