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# Microstructural investigation and lubrication study for single point incremental forming of copper

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ABSTRACT

Lubrication improves surface finish in Single Point Incremental Forming (SPIF). However the reason behind this improvement needs to be investigated. In this study a polycrystalline Copper sheet was incrementally formed to a truncated conical geometry using different lubrications till fracture. The selection of the tool material for optimal surface finish is also discussed. The effect of lubrication on the surface roughness was studied. To understand the effect of the lubrication from a microstructural point of view, Scanning Electron Microscopy (SEM) analysis of the components was carried out. The SEM images from different lubrication states were compared and found that there is some influence of lubrication on the surface. The surface roughness varied along the depth of the formed truncated conical geometry. It was observed that the marks left by the forming tool and the development of valley like structures along the grain boundaries were the cause for increased surface roughness. Other important observation regarding the microstructure study was that due to high strain deformation the grain shape has elongated in its direction. The lubrication conditions had no significant effect on the formed grain size or shape.


## 1. Introduction

Single point incremental forming is a sheet metal forming technique in which the need for a conventional die and punch is eliminated. In this process the sheet metal is rigidly clamped on the rig and numerically controlled forming tool is used to induce the local plastic deformation till the sheet is formed into the desired shape (Jeswiet et al., 2005).

The influence of lubrication on Single Point Incremental Forming (SPIF) of Copper sheet was previously investigated (Jawale et al., 2016) and it was found that lubrication has a positive effect on the surface finish whereas there is no effect on the formability. Scanning electron microscopy (SEM) can be a helpful tool to evaluate the effect of lubrication on a microscopic level (Hu and Liu, 1998). Kim and Park (2002) in their study of SPIF on A1050 sheet metal, concluded that no lubrication state led to scratches on the forming tool and led to more tool wear. The study also stated that the ball tip tool improves formability limits in SPIF, rather than a hemispherical tip forming tool. One of the objectives of this study is to understand the role of the tool material hardness on the tool wear in SPIF.

Hussain et al. (2008) investigated various combinations of tool's material and lubrication to determine their suitability in SPIF of commercially pure titanium (p-Ti) sheet. They used SEM to study the interrelation between the tool and the sheet. They concluded that the sheet surface coating was essential in order to achieve a better surface integrity. Other important parameter to achieve a good surface integrity for p-Ti is the use of HSS tool material and lubrication, with combination of molybdenum disulphide and petroleum jelly in a specific quantity. Zhang et al. (2010) investigated the suitable lubricant and lubricating methods for warm SPIF of magnesium alloy AZ31 sheet. As lubrication $K_2Ti_4O_9$ wisker and solid graphite or $MoS_2$ powder-coated porous ceramic coating by pulsed anodic oxidation was used. They used SEM to study the formed sheet surface and concluded that the above mentioned lubrication coating technique gave a good lubrication performance. In the present study the effect of lubrication on the Copper sheet in SPIF is investigated. SEM analysis is used to understand the influence on the surface of formed sheet metal.

Hamilton and Jeswiet (2010) studied the effect of high feed rate and rotational speed on the grain size of the component formed using SPIF. It was observed that the when the step-down is increased the coarser grains are formed. Ben Hmida et al. (2013) studied the effect of the initial grain size in single point incremental forming of copper. In the study it was concluded that when the ratio between the sheet thickness and

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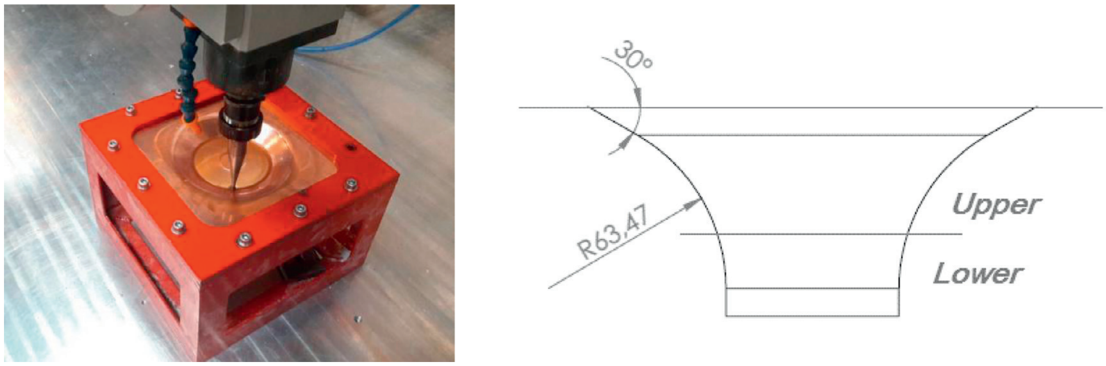


(a) (b)

**Fig. 1.** (a) Cone geometry formed on CNC, (b) geometry of truncated conical geometry.

**Table 1**
Material properties of copper.

| True stress (MPa) | | Elongation [%] | Young's modulus | Anisotropy |
|---|---|---|---|---|
| $\sigma_Y$ | $\sigma_{UTS}$ | | $E$ (MPa) | ($\bar{r}$) |
| 208.9 | 331.3 | 26.7 | 114343.8 | 0.98 |

**Table 2**
Tool material.

| Tool number | Material | Hardness |
|---|---|---|
| 1 | 40CrMnNiMo 8-4-6 steel (PM300) | 310 HB |
| 2 | CK40 | 421 HB |
| 3 | Tungsten-carbide | 2550 HV |

the initial grain size decreased the mechanical properties of the copper decreased and also the formability. In the present study the grain size before and after the SPIF of copper are investigated. The effect of lubrication on the grain size and shape is also studied.

## 2. Experimental setup

In this section the forming tool and the sheet metal material along with their mechanical properties are described. The machine tool used and the adopted methodology are also presented.

### 2.1. Material

Polycrystalline oxygen free 99.9% cold rolled 0.8 mm thick copper sheet metal was used. The material properties of the copper (Table 1) were obtained by conducting tensile tests on an universal testing machine (INSTRON 4507), where the ASTM standard E8/E8M-09 was followed.

Three different forming tool materials with 12 mm diameter were used. Table 2 lists these tool materials along with their hardness.

### 2.2. Single Point Incremental Forming test

The sheet was rigidly clamped using a fixture (Fig. 1a) and was formed using a 5-axis CNC machining centre controlled by a Fagor controller. In SPIF, the forming tool is numerically controlled that describes a trajectory to obtain the final shape of the sheet metal.

The SPIF geometry was the conical geometry, presented in Fig. 1b, and was formed till fracture. For further analysis the conical geometry is divided into two parts, Upper and Lower. The Lower part is the area where the fracture appears; and the Upper is the remaining area.

**Table 3**
Process parameters used for the experiment.

| Spindle speed | Feed rate | Step down | Tool path |
|---|---|---|---|
| Free rotation | 1000 mm/min | 0.15 mm | Spiral |

The process parameters used in this study are presented in Table 3.

### 2.3. Lubrication

The lubricant conditions considered in this study are presented in Table 4. These lubricants have different chemical composition and physical states with significantly varying viscosity, and thus covering a wide variety of lubrication conditions.

The process parameters and the tool path was kept constant throughout the experimental work. The SEM analysis was made by Scanning Electron Microscope with an X-Ray Microanalysis system (brand: JEOL JSM 35C).

### 2.4. Grain structure

In order to study the effect of lubrication on the grain size and shape, the grains boundaries were evaluated before and after the single point incremental forming. The specimens were obtained from fracture zone (lower region) and as received sheet metal. The specimens were mechanically polished along with a solution of OP-S suspension with acid and a solution of dilute hydrogen peroxide with ammonia was used to etch the specimen so that the grain boundaries were visible. The grain boundaries were observed under an optical microscope (Olympus PMG3+ DP25).

## 3. Results and discussion

This section presents a comparison of the different forming tool material and a discussion regarding the surface roughness of the formed components, using SEM analysis.

### 3.1. Tool material selection

In this study, spherical ball end tools with 12 mm diameter were used. In order to study the wear effect of the forming tool in SPIF, three different materials (Table 2) under the same process parameters were used to form the truncated conical shape (Fig. 1b). As a reference test no lubrication state was used for all the tool