Effect of blank-holder force on springback of ultra-thin copper sheets

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Abstract. After forming by plastic deformation, it's rare that the part produced retains its
shape perfectly after removing the tools, the shape and dimensions that the tools imposed on
it. This change in shape is mainly due to springback. This study focuses on the springback of
U-shaped channels made of thin sheets of beryllium copper alloy 0.1 mm thick. The intensity
of springback depends on several factors of part geometry and process parameters. Among
the parameters of the process, we investigated the clamping force, which is an essential factor
influencing the final shape of the part. It is shown that the springback is inversely proportional to
the clamping force. As a consequence, there is no significant change of the geometry of the final
part. Indeed, under high clamping force, the internal stresses (already existing in the material)
become very important, which makes it possible to attenuate significantly the local moment
effect in bending. The result is an uniform distribution of residual stresses in the thickness of
the sheet which is studied in this paper.

1. Introduction
With the increasing demand for micro-parts in recent years which is driven by a significant
trend towards miniaturization in many industrial applications such as electronic devices, medical
deVICES, and even the automotive and aeronautic field [1, 2]. Copper alloys are frequently used
in the electronic industry for both their electrical and mechanical properties, e.g. as leadframes
to support the chip and the leads, that connect electrically the part to its environment [3].
They are used as sheet materials with thickness ranging from about 0.1 mm to about 1 mm,
depending on the application. Such parts are usually obtained via a succession of cutting and
forming steps, the latter being dominated by bending. One of the main issue is therefore to
control springback. Indeed, the springback phenomenon occurs under the action of internal
residual stresses which are not uniformly distributed over the entire thickness of the specimen
after the tools are removed at the end of the sheet forming operation [4]. Springback is sensitive
to many physical parameters including material properties, coefficient of friction, blank-holder
force. From tests on two different materials such as steel and aluminum alloy, Liu et al. [5],
Kim and Koç [6], Lee and Yang [7] were able to show that increasing the blank-holder force
reduces springback. Indeed, for a greater blank-holder force, tensions in the stretched part are
greater thus creating greater strain hardening and considerable plastic deformation throughout
the entire thickness of the specimen. In this work, we characterize springback using U-form
stretch bending tests. Tests are carried out on copper alloy test pieces within a reasonable range
of blank-holder force (before fracture) of the blank to form the part.
2. Experimental procedure

2.1. Materials

The copper beryllium alloy CuBe2 is commonly used for its excellent mechanical characteristics combined with good electrical and thermal conductivity, as well as good resistance to wear and most corrosive media. The rolled sheet has a thickness of 0.1 mm, the chemical composition of which is given in table 1.

Table 1: Chemical composition of CuBe2 in mass percent.

| Element | Mass Percent |
|---------|--------------|
| Cu      | 97           |
| Be      | 1.8 - 2      |
| Co      | 0.3          |
| Ni      | 0.15         |
| Fe      | 0.15         |

The microstructure was measured in the rolling-transverse and transverse-normal sections. Electron Backscatter Diffraction (EBSD) scans identifies the microstructure of the materials. No sensitive microstructure gradient was observed and the grains were considered equiaxed. A pole figure of the microstructure is represented in Figure 1. The grains have an average size of 4µm. The maximum size is 50µm and we have an average of about 25 grains in the thickness.

Figure 1: Pole figure of the copper beryllium alloy CuBe2. Directions are indicated above the figures. [8]

2.2. Process of experiment

A schematic view of the tools of the U-bending process and their dimensions is shown in figure 2. The specimens used to form elongated U-shaped pieces are cut in the rolling direction in a rectangular shape with dimensions 45 mm × 36 mm. A punch stroke of 9 mm is used for all samples and after drawing, tools are removed.
Also springback may decrease with increasing friction caused by surface roughness of both sheet and die. Indeed, in this case the specimen is well deformed and the sliding of the sheet between the tools is difficult. Li et al. [9] have shown that an increase in friction coefficient provokes a decrease in springback angle. It can thus be said that friction plays a role similar to that of blank-holder force. For this no lubricant was used for the tests.

3. Results and discussion

The blank-holder force is a technological factor which has a non-negligible effect on springback. Previous studies have shown that an increase in blank-holder force gives a reduction in springback [6, 10]. Figure 3 shows the variation in the shape of two CuBe2 alloy specimens bent to different blank-holder forces (F=2700 N and F=5500 N). Indeed, the side near the die has tensile stress and the side near the punch has compressing stress, which would promote a residual bending moment and result in side wall curl. Introducing a large blankholder force into the forming process is useful to remove side wall curl [5].

The springback was measured by considering the shapes of the cross-section of the formed parts obtained after the removal of the tools. Three important zones are considered as shown in figure 4. The first zone AB is curved and takes the shape of the cylindrical stretching rod. The second zone BC is slightly curved due to the residual stresses which vary with the sheet thickness. The third zone CD is highly deformed by the stretching effort and bending due to
the entrance curvature of the die. Several studies have been carried out on the change of shape after springback, in which two opening angles of the 2D profile ($\theta_1$ et $\theta_2$) and the curvature radius of the wall $\rho$ are introduced (Figure 4-b).

![Figure 4](image-url)  

**Figure 4:** Schematic representation of the different zones and the specimen shape: (a) Before springback, (b) After springback

The influence of the blank-holder force was studied by analysing the force-displacement curves and comparing the parameters of the springback for each applied clamping condition. Figure 5 shows the effect of the blank-holder force on the experimental force-displacement curve during the experimental U-bending tests. Seven force values were tested. The exerted load by the punch increases with the displacement up to a maximum value for a displacement correspond to 1.4 mm for all the tests. Thus, a significant increase in the maximum punch force about 26% when increasing the blank-holder force from 2700 N to 5500 N. With the increase in black-holder force, flow of the sheet becomes difficult. As a result, the load required to form the sheet increases.
Figure 5: Punch force as a function of punch displacement for different blank-holder force values of the copper beryllium alloy CuBe2

The springback value for the various tests carried out is shown in figure 6. The final geometry of the stamped parts is measured using a laser scanner from the lower surfaces of the U-shaped parts, a data point cloud was created and post-processed to extract the 2D profiles (Figure 6-a) of the part for each imposed condition.

Figure 6-b shows the evolution of the experimental parameters values (θ1 et θ2) for CuBe2 for different blank-holder forces. The evolution of θ1 as a function of the flange length varies between 110° and 120°. The average experimental values for the second characteristic angle θ2 are 55°. The variation of these two angles is less pronounced.

ρ is calculated by fitting a circle with the same radius as the curvature radius of the U-shaped specimen. However, CuBe2 exhibits a large opening characterized by a very low value of about 8.5 mm (Figure 6-c). It is well observed that the higher the blank-holder force, the lower the springback, and this is reflected by the increase of θ2 and ρ, and the decrease of θ1.
We notice that the blank-holder force has a significant influence during the characterization and compensation of the springback of ultra-thin sheets of beryllium copper alloy (Figure 6). Indeed, the magnitude of the tension in the sheet during stretch bending dominates all other physical variables [11]. This is confirmed in numerous springback studies appearing in the literature [6, 10, 7]. In the absence of a blank-holder force, a significant springback is observed.

4. Conclusion
This experimental study focus on studying the springback phenomenon of copper beryllium alloys (CuBe2) for various clamping conditions. A drawing process of U-shaped channels is considered, with rectangular blanks. The forming load and final shape after springback are analysed. It is shown that an increase in blank-holder force reduces sliding of the sheet between the die and the blank holder and reduces springback by increasing the tension. The final springback is the result of a springback in the three characteristic zones of the U-shaped part. These results are also important for the characterization of the bending operation and the
springback compensation of ultra-thin beryllium copper alloy sheets and can be used for the validation of elemental simulations of this forming process.

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