Effects of specimen width and rolling direction on the mechanical properties of beryllium copper alloy C17200

W C Lee1 and Z R Liu

Department of Mechanical Engineering, National Taiwan University of Science and Technology, Taipei, 10607, Taiwan, Republic of China

Email: wclee@mail.ntust.edu.tw

Abstract. The objective of the research was to study the effects of specimen width and rolling direction of beryllium copper alloy, C17200, on the mechanical properties of yield strength and Young’s modulus. The experimental results showed that the reduction of the specimen width from 12.5 mm to 2.5 mm did not affect the yield strength but reduced the Young’s modulus by 4%. Also, the change of rolling direction affected both the yield strength and the Young’s modulus. When the tension direction is parallel to the rolling direction, the maximum yield strength was obtained. The results can help predict the behavior of small-scale beryllium copper products more accurately.

1. Introduction
The current trend for electronic products is towards a small scale; therefore, the sizes of the components in these products need to be reduced as well. When the sizes of the metal parts are reduced, the mechanical properties may change. Research has shown that specimen size does affect the mechanical properties of some metals. Kals et al. [1] found that for CuNi18Zn20 material, the yield strength decreased with reductions in specimen thickness and specimen width. For example, when the thickness of a specimen was reduced from 1.0 mm to 0.1 mm and the width reduced from 20 mm to 2 mm, the yield strength decreased about 15.8%. The study by Reaulea et al. [2] on pure aluminum reported a similar phenomenon. Under the condition that the grain size was less than 126.5 μm, the tensile strength and yield strength were reduced with the reduction of the thickness of the specimen. Dubos et al. [3] found that when the ratio of the specimen’s thickness to the grain size was less than a critical value, highly pure copper became softer in terms of its mechanical properties. Yang and Lu [4] reported similar results, in that the critical value was not a constant but dependent on the grain size. Michael et al. [5] used brass in their study and found a different phenomenon. When the grain size of the specimen was 40 μm and the thickness was 0.1 mm, the tensile tests for five different widths showed that the yield strength decreased with the decrease of the width, but the amount of reduction was small. Therefore, they concluded that the change of width did not affect the flow stress.

Why does specimen size matter in some metals? Miyazaki et al. [6] thought that the surface constraint force was less than the interior constraint force when metals were subjected to loads. The interior of the metal takes more of the load, so when the thickness of the specimen was reduced, the constraint force, as well as the flow stress, was reduced. Engel et al. [7] explained that the hardness of
the grain on the free surface was less than that inside the metal. When the grain sizes were the same, the smaller the diameter of the specimen, the more the surface grains. Because the hardness of the surface grain was less than that of the inside grain, the flow stress decreased.

The rolling direction of the metal is also an important factor when designing electrical spring contacts made of coiled sheet metal. To make the subsequent assembly process easier, the longitudinal direction of the spring contacts is usually perpendicular to the rolling direction of the material. Research has shown that there is no fixed relationship between the mechanical properties of the materials and the angle between the rolling direction and the longitudinal direction in tensile tests. For simplicity, in the following we have used the rolling direction (RD) to represent the angle between the rolling direction and the longitudinal direction in the tensile tests. To illustrate this phenomenon, Leong et al. [8] used annealed α–brass in the tensile tests to obtain the yield strength at 0° and 90°. The average yield strength at 90° was greater than that at 0° by 5.3%. Stachowicz et al. [9] tested 85–15 brass for the yield strength at 0°, 45°, and 90°. The brass was categorized as M85–1, M85–2, M85–3 and M85–4 based on the annealing time. For M85–1 and M85–2, the yield strength was highest at 0°. However, for M85–3 and M85–4, the yield strength was highest at 90°. Therefore, when the annealing conditions were different, the relationship between the rolling direction and yield strength changed as well.

In the connector industry, beryllium copper is a commonly used material for electrical contacts because of its good electrical and mechanical properties. As the size of beryllium copper contacts continues to be reduced, we need to understand if there are any effects on the mechanical properties so that we can predict the behavior of the contacts better. Therefore, one of the objectives of this research was to investigate the change of the yield strength and Young’s modulus of the beryllium copper specimens when the width was reduced; another objective was to investigate those of the beryllium copper specimens at rolling directions of 0°, 45°, and 90°.

2. Experimental methods
The beryllium copper used in this study was C17200–25–1/2 H (TD02). It went through solution heat treatment, then a rolling process and, finally, the annealing condition. The material contained 1.8–2% beryllium. The grain sizes of all the specimens were close and ranged from 6.2 to 9.5 μm; therefore, we did not consider the effect of grain size.

Regarding the design of the experiment, the experimental factors that we selected were width, thickness, and rolling direction. We changed one factor at a time to observe the changes in the yield strength and the Young’s modulus. Because materials with different thicknesses may be from different batches, we did not study further the effect of thickness. When conducting the tensile tests, we used four samples for each condition. The statistical method, analysis of variance (ANOVA), was employed to study the effects due to various widths and rolling directions.

The universal testing machine used was INSTRON 3365. Because the specimens were made of thin metal sheets, we followed ASTM E 8M-01 [10] to design the specimen. The gauge length was 50 mm, and the width was 12.5 mm. Then we modified the design by reducing its width to 7.5 mm and 2.5 mm, respectively. There were four different material thicknesses, 0.05 mm, 0.10 mm, 0.15 mm and 0.20 mm, used in the experiments and rolling directions of 0°, 45°, and 90°. The specimens were prepared by using wire electrical discharge machining. The tests were performed by following ASTM E 345-93. [11] The strain rate was set at 0.01 mm/mm/min to obtain the specimen’s yield strength.

3. Results and discussion
3.1. Effect of specimen width and rolling direction on the yield strength
It was found that the yield strength changed little when the width was reduced from 12.5 mm to 2.5 mm. By using the specimen with a thickness of 0.05 mm and a rolling direction of 0°, we plotted the experimental results as shown in Figure 1 We then used ANOVA to analyse the data further. The ANOVA result is listed in Table 1. The confidence level adopted for the analysis was 95%. From the
F-ratios and the p-values in Table 1, we found that the p-value associated with the width factor was 0.133, which was greater than the α risk of 0.05; therefore, the width was not a significant factor for yield strength. Figure 2 shows the main effect plots associated with the effects of width, thickness and rolling direction on the yield strength. It can be seen that the yield strength remained about the same for the different widths, ranging between 580 MPa and 582 MPa. This phenomenon was similar to the conclusion made by Michel et al. [5] concerning brass.

As shown in Table 1, the p-value associated with the rolling direction factor was minimal, and less than the α risk at 0.05. Therefore, the rolling direction was a significant factor for yield strength. It can be seen from Figure 2 that the average yield strength was 611 MPa when the rolling direction was 0°, which was about 7% more than the average yield strength for rolling directions of 45° or 90°. This result was different from the results for copper alloy and aluminum alloy obtained in previous research. The reason may be related to the composition of the beryllium copper and the annealing conditions.

![Figure 1](image.png)

**Figure 1.** Yield strength associated with various widths for the thickness of 0.05 mm and the rolling direction of 0° (RD: rolling direction, t: thickness, Sy: yield strength, w: width).

Also, we observed that materials with different thicknesses can have obviously different average yield strengths, which were as high as 602 MPa and as low as 566 MPa. This variation was consistent when the results were compared with the inspection report provided by the vendor of the material. So, the variations in the yield strength of materials with different thicknesses could be due to their different metal compositions and different manufacturing conditions, with the variation not only a result of the thickness.
Table 1. ANOVA results regarding the yield strength.

| Source   | Sums of Squares | Degrees of Freedom | Mean Squares | F-ratio   | p-value |
|----------|-----------------|--------------------|--------------|-----------|---------|
| w        | 76              | 2                  | 38           | 2.06      | 0.13    |
| RD       | 61457           | 2                  | 30729        | 1668.32   | 0.00    |
| t        | 24617           | 3                  | 8206         | 445.49    | 0.00    |
| w×RD     | 77              | 4                  | 19           | 1.05      | 0.39    |
| w×t      | 387             | 6                  | 64           | 3.50      | 0.00    |
| RD×t     | 7753            | 6                  | 1292         | 70.15     | 0.00    |
| w×RD×t   | 182             | 12                 | 15           | 0.83      | 0.63    |
| Error    | 1989            | 108                | 18           |           |         |

3.2. Effect of specimen width and rolling direction on the Young’s modulus

Based on the experimental results, we found that both the width and the thickness affected the Young’s modulus. For example, Figure 3 shows the Young’s modulus at different widths, when the thickness was 0.05 mm and the rolling direction was 0°. As the width decreased, the Young’s modulus also decreased. As the ANOVA results listed in Table 2 show, the p-values of the width and the rolling direction were minimal, which meant that the width and the rolling direction did affect the Young’s modulus. In addition, the F-ratio of the thickness was 3.87 and the p-value of the thickness was 0.01, which meant that the thickness also affected the Young’s modulus; however, the effect was not as obvious as for the width or rolling direction.
The effects of thickness, width, and rolling direction on the Young’s modulus were plotted in Figure 4. It can be seen that the average Young’s modulus was 125 GPa when the width was 12.5 mm. Compared to the average Young’s modulus of 120 GPa when the width was 2.5 mm, the Young’s modulus showed a decrease of about 4.4%.

**Figure 3.** Young’s modulus associated with various widths for the thickness of 0.05 mm and the rolling direction of 0°.

**Figure 4.** Main effect plots of thickness, width and rolling direction regarding the Young’s modulus.
Regarding the rolling direction, the average Young’s modulus was 126 GPa and 125 GPa for a rolling direction of 0° and 90°, respectively. The difference here was negligible. However, the average Young’s modulus was 118 GPa when the rolling direction was 45°, which was about 6.5% less than that for a rolling direction of 0°. It can also be seen in Figure 4 that there was no obvious difference in the Young’s modulus when the thickness varied. The range was from 122 GPa to 124 GPa.

Table 2. ANOVA results regarding the Young’s modulus.

| Source | Sums of Squares | Degrees of Freedom | Mean Squares | F-ratio | p-value |
|--------|-----------------|--------------------|--------------|---------|---------|
| W      | 773.17          | 2                  | 386.58       | 41.29   | 0.00    |
| RD     | 2066.38         | 2                  | 1033.19      | 110.34  | 0.00    |
| T      | 108.74          | 3                  | 36.25        | 3.87    | 0.01    |
| w×RD   | 27.96           | 4                  | 6.99         | 0.75    | 0.56    |
| w×t    | 106.44          | 6                  | 17.74        | 1.90    | 0.09    |
| RD×t   | 249.57          | 6                  | 41.60        | 4.44    | 0.00    |
| w×RD×t | 171.93          | 12                 | 14.33        | 1.53    | 0.12    |
| Error  | 1011.25         | 108                | 9.36         |         |         |

4. Conclusions
In our study, for the material C17200–25–1/2H (TD02), when the widths ranged from 2.5 mm to 12.5 mm, the thicknesses ranged from 0.05 mm to 0.20 mm and the rolling directions ranged from 0° to 90°; the change of the width of the specimen did not affect the yield strength, but did affect the Young’s modulus. When the width was reduced from 12.5 mm to 2.5 mm, the Young’s modulus was reduced by about 4.4%.

On the other hand, under the same condition, the change of the rolling direction of the specimen did affect both the yield strength and the Young’s modulus. When the rolling direction was 0°, the yield strength and the Young’s modulus were at their maximum. When the rolling direction was 45°, the yield strength and the Young’s modulus were at their minimum. The difference for the yield strength was about 7%, and the difference for the Young’s modulus was about 6.5%. When the rolling direction was 90°, the yield strength was close to that at 45° and the Young’s modulus was close to that at 0°.

Based on the above results, when a finite element software tool is used to analyse a tiny component made of beryllium copper, if the longitudinal direction of the component is perpendicular to the rolling direction, it is necessary to consider lowering the allowable stress. If the width of the component is as little as 2.5 mm, we need to consider reducing its Young’s modulus. By so doing, the accuracy of the analysis results should be improved.

References
[1] Kals T A and Eckstein R 2000 Miniaturization in sheet metal working. J. Mater. Process. Tech. 103, 95-101.
[2] Raulea L V, Goijaerts A M, Govaert L E, and Baaijens F P T 2001 Size effects in the processing of thin metal sheets’, J. Mater. Process. Tech. 115, 44-48.
[3] Dubos P A, Hug E, Thibault S, Gueydan A, and Keller C 2013 Strain path influence on size effects during thin sheet copper microforming. Int. J. Mater. Prod. Tec. 47, 3-11.
[4] Yang L and Lu L 2013 The influence of sample thickness on the tensile properties of pure Cu with different grain sizes Scripta Mater. 69, 242-245.
[5] Michel J F and Picart P 2003 Size effects on the constitutive behaviour for brass in sheet metal forming J. Mater. Process. Tech. 141, 439-446.

[6] Miyazaki S, Shibata K, and Fujita H 1979 Effect of specimen thickness on mechanical properties of polycrystalline aggregates with various grain sizes. Acta Metall. 27, 855-862.

[7] Engel U and Eckstein R 2002 Microforming - From basic research to its realization J. Mater. Process. Tech. 125-126, 35-44.

[8] Leong W and Nourbakhsh S 1989 Tensile behavior of cold rolled α-brass Scripta Metall. 23, 1011-1014.

[9] Stachowicz F 1989 Effects of microstructure on the mechanical properties and limit strains in uniaxial and biaxial stretching. J. Mech. Work. Technol. 19, 305-317.

[10] ASTM, E8M-01 2003 Standard Test Methods for Tension Testing of Metallic Materials. [Metric]

[11] ASTM 2003 E345-93, Standard Test Methods of Tension Testing of Metallic Foil.