The Effect of Reduction Cross Section Area and Rolling Temperature in Mechanical Properties of Al-Cu

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Abstract. Aluminium is one of the materials that mostly used in the industry after iron and steel. One of the methods that can be used to optimize their mechanical properties is a rolling process. However, the rolling process cannot be obtained at a low temperature since the formability of Al- Cu quite low. According to this research, the rolling process carries out at a high temperature; it is above its recrystallization temperature. The point of this research is to discern the maximum reduction in the temperature of 300°C, 400°C and 500°C and the influence of the mechanical properties. Based on the research the result shows us the higher temperature in hot rolling (300°C, 400oC, and 500°C), it can decrease 7.1% the hardness value but it can increase 550% the cross-section reduction. However, the toughness value of the material will increase. It shows us from the result of tensile strain up to 18%, the result of yield strain up to 130.77% and the elongation value up to 600%. The increasing of temperature in hot rolling in Al-Cu 2024 to achieve the formation of the intermetallic unit on intergranular grain finer.

Keywords: rolling, intermetallic, reduction, recrystallization

1. Introduction

The cold rolling process has been proved to improve the surface density, surface roughness, abrasion resistance, and other properties of the surface layer. The warm rolling process is based on the ordinary cold rolling surface densification process, but has an extra heating process. Based on cold rolling technology, warm rolling is likely to further improve performance with the plastic deformation of the parts. When the warm rolling process is conducted, the parts are deformed under a certain temperature range, which is usually higher than the recovery temperature but lower than the recrystallization starting temperature [6]. During the process of warm deformation, work hardening will take place in the samples, accompanied by dynamic recovery softening and static softening within the gap moment of the deformation, although the work hardening effect is dominant [7]. The hardness and yield strength of the metals are dependent on the degree of work hardening and softening [8]. Compared with Cold deformation, during the warm deformation process metal have relative low yield strength, high plasticity and low deformation resistance.

Microscopically, deformation can be seen as a change in shape and size. Shape changes that occur can be distinguished from elastic deformation and plastic deformation. Shape changes can be separated into two, namely:
1. Elastic Deformation.
Elastic deformation is a change in shape that occurs when there is force acting, and will disappear if the load is removed. In other words, if the load is removed then the work piece will return to its original shape and size.

2. Plastic Deformation.
Plastic deformation is a permanent deformation, even though the burden is removed. The increase in strength of each type of metal and its alloys as a result of cold working is very dependent on the increase in its dislocation density. A high dislocation density makes the metal more difficult to form, and at one time becomes so fragile that it cannot be deformed again. To return to its original properties, which are soft and ductile, it is necessary to heat the work piece which has experienced cold working.

In studying the characteristics of Al-Cu alloys by the casting method, it is first necessary to understand the phase balance diagram of the alloy. This aims to make it easier to identify the phases that occur during the melting and freezing process. Al-Cu alloy system which is displayed in the form of Al-Cu binary balance diagram can be seen in Figure 1. This shows that under pure conditions aluminum metal (Al) has a melting point of 660°C and copper metal (Cu) has a melting point of 1533°C. In solid conditions, the solubility of Cu in aluminum reaches 5.65% Cu at 548°C. Phases contained in Al-Cu alloys consist of α and CuAl2 phases. The formation of this phase is highly dependent on the chemical composition of the alloy.

![Fig. 1. Fase diagram Al-Cu](image)

2.Materials and Method

2.1 Making Samples for Scaling Process Simulation
Sampling for simulating the rolling process is intended to get the maximum reduction in cross section. The reduction of the maximum cross-sectional area is
determined based on its formability. Sampling for the rolling process simulation is done by machining process. The shape and size of the sample, as shown in Figures 2.

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![Figure 2. Shape and size of the sample rolling process simulation](image)

The shape and dimensions of the above sample are made thin with maximum thickness (A) and minimum (B) respectively 10 mm and 2.5 mm. The length of the inclined plane (D) is 150 mm and the total length (E) of the simulated sample is 190 mm.

The equation used in the calculation of the amount of reduction is, as follows:

$$\text{Cross – Section reduction} = \frac{T_{\text{input}} - T_{\text{output}}}{T_{\text{output}}} \times 100\% \quad (3-1)$$

Where:

- \(T_{\text{input}}\): plate thickness before rolled, mm
- \(T_{\text{output}}\): plate thickness after rolled, mm

Based on the image data, the maximum and minimum reduction can be calculated:

Maximum cross-sectional reduction = \(100\% \times \frac{10 \text{ mm} - 2.5 \text{ mm}}{2.5 \text{ mm}}\)  
= 300 %

Minimum cross-sectional reduction = \(100\% \times \frac{2.5 \text{ mm} - 2.5 \text{ mm}}{2.5 \text{ mm}}\)  
= 0 %
Table 1. Cross Area reduction on simulation sample

| Line | Section | Initial thickness (mm) | Final thickness (mm) | Reduction (%) |
|------|---------|------------------------|----------------------|---------------|
| 1    | 0       | 2.50                   | 2.5                  | 0             |
| 2    | 1       | 2.50                   | 2.5                  | 0             |
| 3    | 2       | 2.50                   | 2.5                  | 0             |
| 4    | 3       | 3.00                   | 2.5                  | 20            |
| 5    | 4       | 3.50                   | 2.5                  | 40            |
| 6    | 5       | 4.00                   | 2.5                  | 60            |
| 7    | 6       | 4.50                   | 2.5                  | 80            |
| 8    | 7       | 5.00                   | 2.5                  | 100           |
| 9    | 8       | 5.50                   | 2.5                  | 120           |
| 10   | 9       | 6.00                   | 2.5                  | 140           |
| 11   | 10      | 6.50                   | 2.5                  | 160           |
| 12   | 11      | 7.00                   | 2.5                  | 180           |
| 13   | 12      | 7.50                   | 2.5                  | 200           |
| 14   | 13      | 8.00                   | 2.5                  | 220           |
| 15   | 14      | 8.50                   | 2.5                  | 240           |
| 16   | 15      | 9.00                   | 2.5                  | 260           |
| 17   | 16      | 9.50                   | 2.5                  | 280           |
| 18   | 17      | 10.00                  | 2.5                  | 300           |
| 19   | 18      | 10.00                  | 2.5                  | 300           |
| 20   | 19      | 10.00                  | 2.5                  | 300           |

Fig.3. Specimens of test

The shape of the tensile test rod is made according to ASTM B 557 M standards [4], as shown in Figure 3.
3. Results and Discussion.

Figure 4. The shape and size of ASTM B 557 M standard tensile test specimens

| Diameter | Dimensi, mm | Normal | Specimen Standart | Small-Size Specimen | Proportional to Standart |
|----------|-------------|--------|-------------------|----------------------|-------------------------|
|          |             |        |                   |                      |                         |
| G        | 62,50 ± 0,10| 45,00 ± 0,09| 30,00 ± 0,06     | 20,00 ± 0,04         |
| L        | 12,50 ± 0,25| 9,00 ± 0,10 | 6,00 ± 0,10      | 4,00 ± 0,05          |

Chemical analysis result

| Chemical composition | Element | Si | Mg | Cu | Fe | Mn | Ni | Al |
|----------------------|---------|----|----|----|----|----|----|----|
| % weight             |         |    |    |    |    |    |    |    |
| 0,25                 | 1,52    | 4,32| 0,5| 0,84| 0,005| 92,35|

Figure 5. Samples resulting from the rolling process at a reduction of 5, 10 and 15%
Table 2. Hardness Number

| Rolling Processes | Hardness Value (HV) | Average (HV) |
|-------------------|---------------------|--------------|
|                   | I       | II      | III     |         |
| Temperature       | Reduction |         |         |         |
| 200°C*            | 5%       | 90      | 95      | 93 HV   |
| 200 °C*           | 10%      | 100     | 99      | 100 HV  |
| 200 °C*           | 15%      | 106     | 107     | 106 HV  |
| 200 °C*           | 20%      | 106     | 107     | 106 HV  |
| 300 °C            | 40%      | 100     | 93      | 98 HV   |
| 400 °C            | 180%     | 85      | 85      | 94 HV   |
| 500 °C            | 260%     | 91      | 92      | 91 HV   |

Table 3. Tensile Strength (N/mm²)

| Rolling Processes | Tensile Strength, \(\sigma_t\) |
|-------------------|-------------------------------|
|                   | Temperature | Reduction |         |         |
| 200°C*            | 5%          |           | 204,75 N/mm² |
| 200 °C*           | 10%         |           | 286,24 N/mm² |
| 200 °C*           | 15%         |           | 293,16 N/mm² |
| 200 °C*           | 20%         |           | -        |
| 300 °C            | 40%         |           | 268,04 N/mm² |
| 400 °C            | 180%        |           | 270,89 N/mm² |
| 500 °C            | 260%        |           | 315,91 N/mm² |
This is evidenced by experiments through the rolling process at a variation of the cross section reduction of 5%, 10%, 15% and 20%. Then after hardness testing is carried out as shown in figure 1 which is plotted in a graphical it appears that the hardness value tends to increase with the amount of reduction given at a temperature of 200°C. At 5% reduction, the hardness value obtained reaches 88.83% and the greater the reduction given the increase in the hardness value increases again. The increase in hardness value is caused by strain hardening and not by strengthening from the second phase (CuAl2 precipitates).
The value of tensile strength has been changed by the variation of the cross section reduction of 5%, 10% and 15%. The value of its tensile strength increases with increasing cross-section reduction. At 5% reduction, the value of the tensile strength obtained reaches 204.75 N / mm² and the greater the reduction given the increase in the value of tensile strength increases but is followed by decreasing formability. This is indicated by the results of hot rolling at a temperature of 200°C with a reduction in cross-section of 20%, which is not capable.

At a reduction of 5%, the yield strength value obtained reaches 142 N / mm² and the greater the reduction given the increase in the yield strength value also increases. As with the 15% reduction, the yield strength value obtained was 260.58 N / mm². Then after doing the research by varying the rolling temperature of 300°C, 400°C and 500°C and each was carried out at its maximum reduction. The experimental results show that the yield strength value is lower than the yield strength value obtained at 200°C rolling temperature with a maximum reduction of 15%.

Where the 5% reduction, the elongation value obtained reaches 8%, but the greater the reduction given the percentage of elongation, the decreases it reaches 4% at the 15% reduction in cross-section. This is because the sample has increased its elasticity.

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4. Conclusions
From the description above, a number of conclusions can be drawn, as follows:

a) As heat curling temperatures increase (300°C, 400°C, 500°C) the hardness value decreases by 7.1%, but the reduction in the appearance increases to 550%.

b) The increasing heat rolling temperature the material strength value increases. The tensile strength value reaches 18%, the value of the melt strength reaches 130.77% and the extension value reaches 600%.

c) Increasing the heat rolling temperature, the formation of compounds at the grain boundaries is getting smoother.

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