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Original scientific paper

INFLUENCE OF COLD ROLLING AND ANNEALING ON THE HARDNESS OF Cu-Al BIMETALLIC STRIP

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Abstract
Cu–Al bimetallic strips were subjected to cold rolling with varying degrees of thickness reduction, followed by annealing of the most severely deformed samples at different temperatures for one hour. The hardness of the constituent layers was determined as a function of both deformation degree and annealing temperature. The results revealed a systematic increase in hardness with progressive deformation: the aluminum layer exhibited an almost linear dependence, while the copper layer displayed a three-stage response. In contrast, annealing at elevated temperatures induced a pronounced reduction in hardness in both aluminum and copper layers.

Keywords: *bimetallic strip, hardness, deformation degree, annealing*

1. INTRODUCTION

Bimetallic materials are increasingly used because they combine the advantageous properties of different metals within a single structure. Copper-aluminum (Cu-Al) bimetallic strips are of particular interest due to their favorable electrical, thermal, and mechanical characteristics. Cold rolling is a common processing method that ensures bonding between the layers and significantly affects hardness through work hardening. On the other hand, annealing reduces internal stresses and enables recovery and recrystallization, leading to changes in mechanical properties. This study investigates the combined effect of cold rolling and annealing on the hardness of Cu-Al bimetallic strips, with the aim of better understanding the relationship between processing conditions and material performance.

2. EXPERIMENTAL

Specimens were prepared from a Cu–Al–Cu plate, 10.4 mm thick, produced by explosive cladding. After removing one copper layer, bimetallic strips of 8.4 mm were obtained, consisting of 6.4 mm Al and 2 mm Cu. Rolling was carried out in multiple passes with a reduction of 2.5% per pass until total reductions of 10%, 20%, 30%, 40%, 50%, 60%, 70%, and 80% were achieved. After each deformation level, the strip thickness and individual layer thicknesses were measured.

The samples deformed with maximum deformation degree, ε_{max}=80%, were subjected to annealing. Annealing was carried out in a protective nitrogen atmosphere for one hour at temperatures of 200, 250, 300, and 400 °C.

Hardness measurements were performed after all degrees of deformation and after the annealing.

The experimental flow is shown schematically in figure 1.

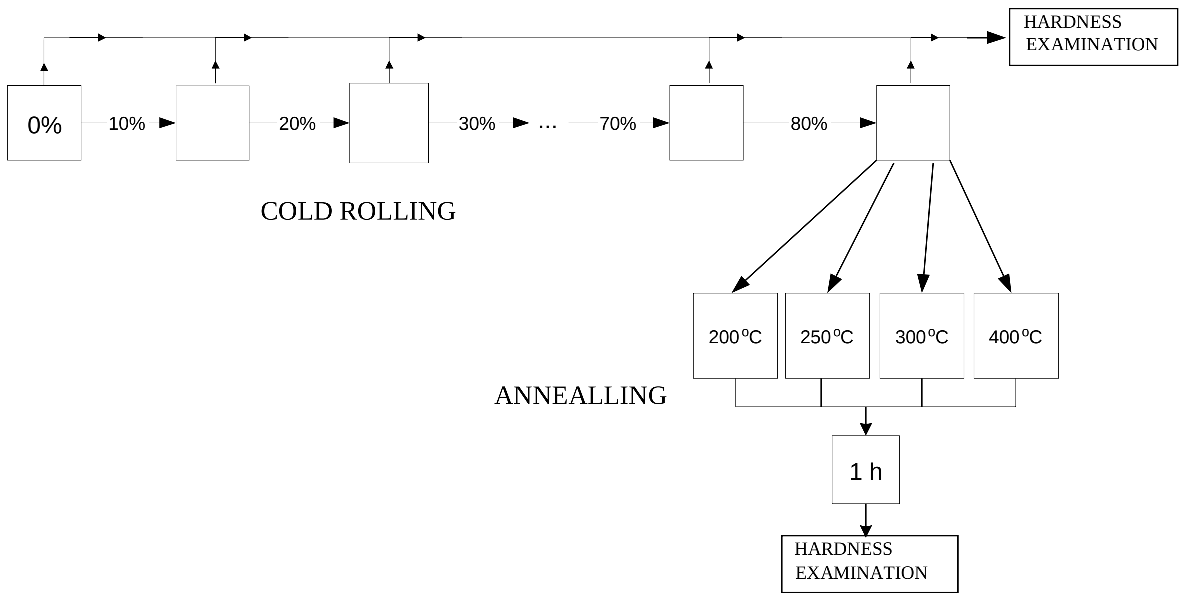

Figure 1. Schematic diagram of the experimental flow

3. RESULTS AND DISCUSSION

The obtained data for the hardness measurements, depending on the total deformation degree are given in Table 1. and Figure 2.

Table 1. Dependence of the hardness of bimetallic strip layers on the degree of deformation

ε (%)	HV (daN/mm²)	
	Al	Cu
0	43.83	106.00
10	44.20	115.75
20	46.33	117.00
30	47.27	120.40
40	48.04	121.67
50	48.44	125.50
60	49.20	131.80
70	49.80	136.00
80	51.05	146.75

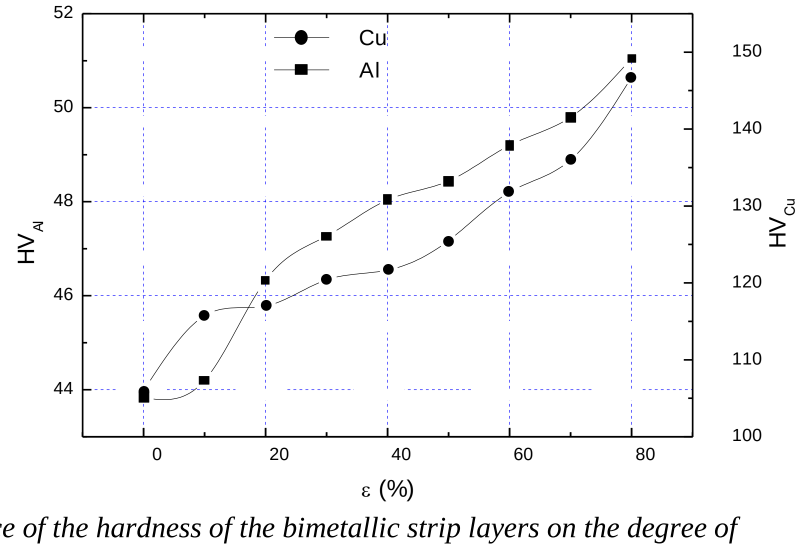

Figure 2. Diagram of the dependence of the hardness of the bimetallic strip layers on the degree of deformation

From the diagram, it can be seen that the overall trend of the hardness–total deformation curves is increasing, with the hardness of aluminum rising approximately linearly with the increase in the degree of deformation.

The hardness–deformation dependence curve of the copper layer can be divided into three parts.

In the first part of the curve, up to 10% deformation, the hardness of the copper layer increases sharply; in the second part, up to 50% deformation, it rises slowly, and then it increases again more rapidly until reaching the maximum value of 146.75 daN/mm² at a total deformation of the bimetallic strip of 80%.

In addition to the observed hardness changes, it should be emphasized that the linear increase in the hardness of the aluminum layer reflects its limited work-hardening capacity due to its high stacking fault energy. In contrast, copper exhibits a more complex three-stage hardening response, characteristic of materials with lower stacking fault energy where dynamic recovery processes occur more gradually.

Samples with a total deformation degree of ε = 80% were annealed for one hour in a protective nitrogen atmosphere at different temperatures (200°C, 250°C, 300°C, 400°C).

The obtained hardness (HV) test results as a function of annealing temperature are presented in Table 2 and in the diagram shown in Figure 3.

Table 2. Dependence of the hardness of bimetallic strip layers on the annealing temperature

t(°C)	**HV (daN/mm^2)**	
	Al	**Cu**
200	42.30	137.00
250	40.12	130.50
300	28.86	63.52
400	25.57	55.72

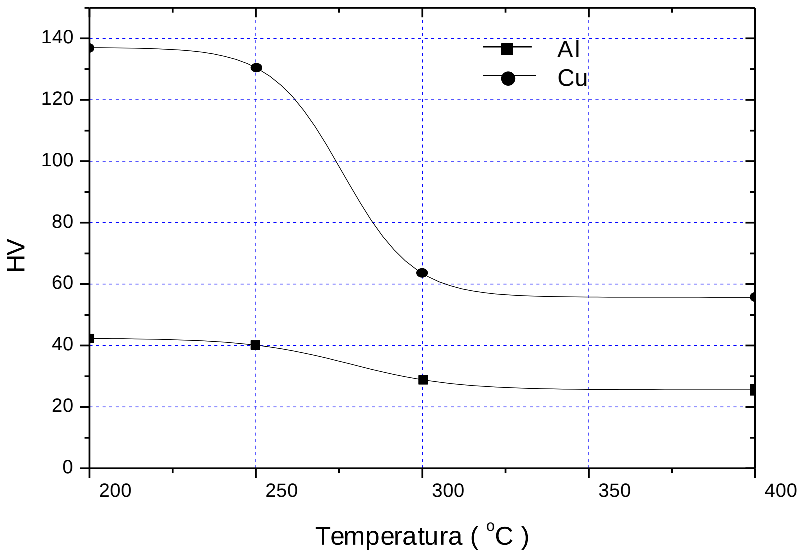

Figure 3. Diagram of the dependence of the hardness of the bimetallic strip layers on the annealing temperature

From the figure, a decrease in hardness with increasing annealing temperature can be observed, both in the aluminum layer and in the copper layer.

It can be seen that the hardness decreases slightly up to T = 250°C, after which it drops sharply in both layers in the temperature range of 250–300°C, when recrystallization of both layers occurs [6,7].

With further increases in annealing temperature up to 400°C, no significant additional reduction in the hardness of the layers is observed.

The sharp drop in hardness in the range of 250–300 °C is a clear indication of recrystallization in both layers, consistent with recent findings in Cu–Al laminated composites [1,3,6,7]. These results highlight the importance of controlling rolling reduction and annealing schedules in order to balance hardness and ductility. Similar behavior has been reported in other laminated systems where recrystallization strongly influences mechanical performance [2,4,9]. The industrial relevance of these findings lies in the optimization of Cu–Al laminates for applications such as electrical connectors and thermal conductors, where a trade-off between hardness and conductivity must be carefully managed [5,8,10].

4. CONCLUSION

The overall trend of the hardness–total deformation curves is increasing, with the hardness curve for aluminum being approximately linear and always lower than the hardness curve for copper, whose progression can be divided into three parts. These findings contribute to a clearer understanding of the deformation and annealing behavior of Cu–Al laminates, with practical implications for tailoring processing routes to achieve desired mechanical performance [2,4,9]. Future research should focus on microstructural characterization (SEM/TEM) to confirm recrystallization mechanisms, as well as on the relationship between hardness and other functional properties such as electrical conductivity.

With increasing annealing temperature of the cold-deformed bimetallic strip (ε = 80%), the hardness decreases in both the aluminum and copper layers—slightly up to 250°C, and then sharply in the range of 250°C to 300°C, when recrystallization of both layers occurs [6,7].

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REFERENCES

[1] J. Chen, Y. Li, P. Liu, X. Zhang, H. Zhou., M. Sci. Eng. A., 835 (2022) 142642.
[2] L. Wang, Y. Zhao, Z. Sun, Q. Liu., J. Alloys Compd., 872 (2021) 159685.
[3] S. Zhang, W. Li, K. Chen, J. Yang., Materials Characterization, 169 (2020) 110606.
[4] C. Lee, J. Park, S. Kim., Metals, 12 (4) (2022) 673.
[5] F. Gao, Y. Yuan, Z. Chen., Materials, 12 (23) (2019) 3871.
[6] J. Xu, G. Huang, Y. Liu., J. Mater. Res. Technol., 12 (2021) 1284–1293.
[7] H. Li, J. Zhou, X. Wang, MSF, 1085 (2023) 233–240.
[8] H. Park, M. Choi, S. Yoon, Mater. Sci. Technol., 36 (15) (2020) 1645–1653.
[9] T. Zhao, J. Sun, Y. Wu., J. Mater. Process. Technol., 302 (2022) 117497.
[10] Y. Lin, Y. Zhang, Q. Chen., Mater. Today Commun., 28 (2021) 102595.