International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:8, No:2, 2014

Cladding of Al and Cu by Differential Speed Rolling

Tae Yun Chung, Jungho Moon, Tae Kwon Ha

Abstract—Al/Cu clad sheet has been fabricated by using differential speed rolling (DSR) process, which caused severe shear deformation between Al and Cu plate to easily bond to each other. Rolling was carried out at 100 and 150°C with speed ratios from 1.4 to 2.2, in which the total thickness reduction was in the range between 14 and 46%. Interfacial microstructure and mechanical properties of Al/Cu clad were investigated by scanning electron microscope equipped with energy dispersive X-ray detector, and tension tests. The DSR process was very effective to provide a good interface for atoms diffusion during subsequent annealing. The strength of bonding was higher with the increasing speed ratio. Post heat treatment enhanced the mechanical properties of clad sheet by forming intermetallic compounds in the interface area.

***Keywords*—**Aluminum/Copper clad sheet, Differential speed rolling, Interface microstructure, Annealing, Tensile test.

I. Introduction

DIFFERENTIALspeed rolling (DSR) processes, for which the peripheral velocity or radius of the upper roll may be different from those of the lower roll, have become more and more important in the light of the fact that it can gain such advantages as lower rolling pressure distribution, resulting in less rolling force and less torque. The benefits for the reduced rolling force are as follows: (1) improved properties of the sheet surfaces can be obtained; (2) shape and thickness can be easily controlled; (3) reduction can be increased and the number of rolling pass can be decreased; (4) rolling process for the high tensile strength materials and extremely thin strip can be possible; (5) energy can be saved by the decrease of annealing heat treatment; etc [1]. The disadvantages of DSR process, however, are mill vibration and wrinkles on the sheet surface.

In the meantime, several processes have been employed to fabricate bimetal clad sheets, such as explosive welding, diffusion bonding, roll bonding, friction stir welding (FSW), and laser welding [2]. The cold roll bonding is known to be more efficient and economical than the other methods [3]. A sound bonding is achieved when surface deformation breaks up the contamination layers and roll pressure causes the extrusion of material through any cracks present in fractured surface [4].Differential speed rolling process has shown that the cross shear deformation zone was caused by the displacement of neutral plane of upper and lower roll, providing a severe deformation for materials and lessening the power consumption. In addition, this method improves the interfacial bonding of clad sheet [5], consequently regarded desirable to bond dissimilar component metal, especially for which are difficult to deform.

T. Y. Chung and J. Moon are with the Department of Electrical Engineering, and T. K. Ha is with the Department of Advanced Metal and Materials Engineering, Gangneung-Wonju National University, 120 Gangneung-Daehangno, Gangneung, Gangwon 210-702, South Korea (phone: 82-10-2367-1989; e-mail: tkha@gwnu.ac.kr).

Clad sheet has drawn a growing interest for cost reduction, especially combining the advantages of high specific conductivity and good resistance to corrosion. The sheet shows high formability, electrical and thermal conductivity, making it a promising material for specific application in automobile and electronics industries. However, fabrication of Cu/Al clad sheet is a great challenge due to the different chemical and physical properties of constituent metals. The formation of brittle intermetallic phase, known to be formed at elevated temperature (Cu_xAl_y), deteriorates significantly the interface bonding [2].

In the present study, Cu/Al clad sheets were fabricated by DSRprocess, which is operated at 100 and 150°C with speed ratios of 1.4 and 2.2. Interface microstructure observation, post heat treatment, and mechanical tests were carried out to establish the most optimal process condition.

II. Experimental Procedure

TABLE I
SPECIFICATION OF THE RAW MATERIALS USED IN THIS STUDY

Material	Chemical composition (wt.%)	Tensile strength (MPa)	Elongation (%)
AA3003	98.8Al, 1.2Mn	140	23
C11000	99.9Cu	210	24

The raw materials used in this study were commercial AA3003 with thickness of 2 mm and pure copper sheets (C11000) with thickness of 0.3 mm in fully annealed condition, of which the specifications are given in Table I. The hot rolling bonding experiments were carried out at 100 and 150°C with speed ratios of 1.4 and 2.2. The total thickness reduction was in the range from 14 to 46%.To remove presumably existing oxides, adsorbed ions, greases and dust particles on the surface of raw materials, the metal surface was degreased in acetone for 5min, and then scratched using circumferential brush with 0.3 mm diameter stainless steel wires running at 120 rpm. The scratching process was essential to remove surface oxides as well as to create a work-hardened surface layer [6]. The component metals were stacked together by a soft aluminum wire in the means of copper lying underneath aluminum. The stack combination was fed into the rolling mill without lubrication.

The clad sheets were heat-treated to reduce the residual stress and enhance the effect of precipitation hardening in a furnace at 400°C for 30 to 120min under the pressure of 1×10^{-4}torr, followed by air cooling, as shown in Fig. 1. The cross-section of samples were ground and polished following the standard metallographic procedures, and etched in a solution of 5ml HNO_3 + 3ml HCl + 2ml HF + 190ml H_2O.

International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:8, No:2, 2014

Interfacial microstructure and chemical composition were analyzed using scanning electron microscope (SEM) equipped with energy dispersive X-ray detection (EDS).

For clad samples, tensile test was carried out at room temperature under the strain rate of 5×10^{-4} s^{-1}, using specimens with gage length of 12mm and thickness of 2mm prepared by EDM.

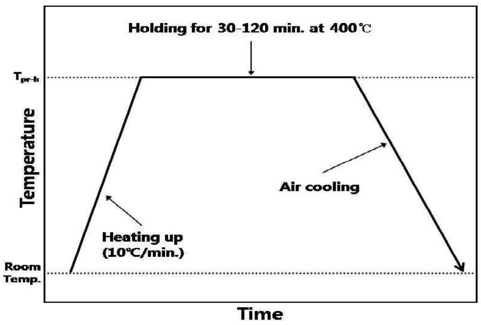

Fig. 1 Schematic illustration of heat-treatment conducted after cladding by DSR process

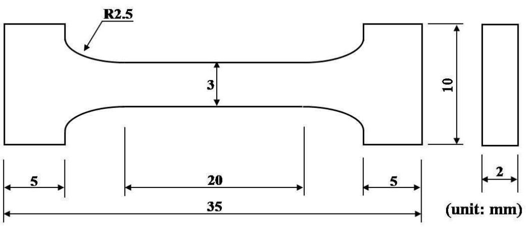

Fig. 2Specifications of tensile specimens used in this study

III. Results and Discussion

Fig. 3 shows appearances of clad sheets hot-rolled at 150°C under the speed ratio of 2.1:1 with various thickness reductions. As shown in Fig. 3, cladding was not completed under these conditions.

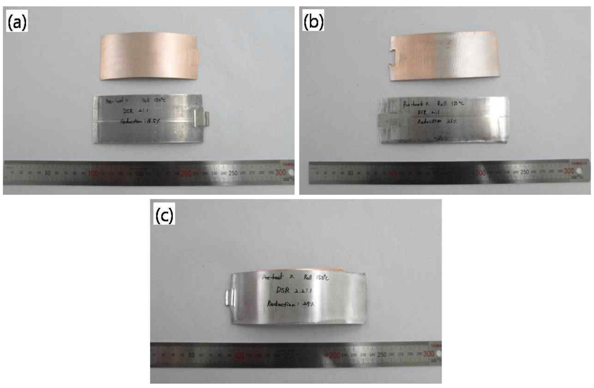

Fig. 3 Appearances of hot-rolled sheets processed by DSR at 150°C under the speed ratio of 2.1:1 with thickness reductions of 16.5% (a), 26% (b), and 27% (c), respectively

Fig. 4 shows appearances of clad sheets hot-rolled at 100°C under the speed ratio of 2:1 with various thickness reductions. Although the rolling temperature decreased, cladding was successfully completed, showing sound interfaces regardless of thickness reductions. It is interesting to note that shear deformation of Al sheet is much severer than that of Cu.

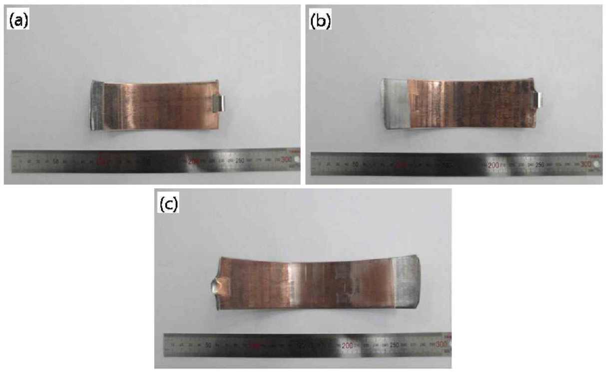

Fig. 4 Appearances of hot-rolled sheets processed by DSR at 100oC under the speed ratio of 2:1 with thickness reductions of 24% (a), 36% (b), and 45% (c), respectively

Results of interface observation are illustrated in Fig. 5, and upper part is pure Cu and lower one Al 3003. Any void or crack could not be observed as shown in the figures.

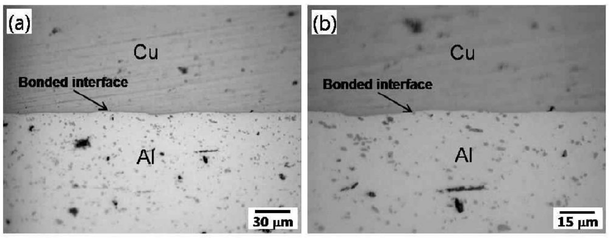

Fig. 5 Optical micrographs showing interface of cladded sheet obtained at 100°C under the speed ratio of 2:1 with thickness reductions of 45%

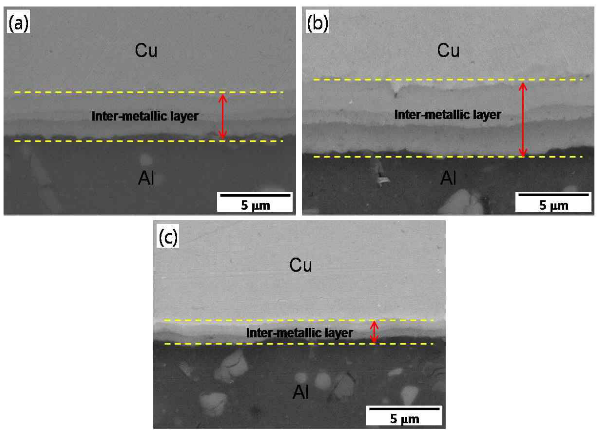

Fig. 6 SEM micrographs showing interface of cladded sheet obtained at 100°C under the speed ratio of 2:1 with thickness reductions of 45% followed by annealing at 400°C for 30 (a), and 60 (b), and 120 min (c), respectively

Fig. 6 shows interface area observed by SEM on the specimens annealed at 400°C for 30 to 120 min after hot-rolling at 100°C under the speed ratio of 2:1 with thickness reduction of 45%. It is obvious that intermetallic layer of above 3μm thickness was formed and any delamination of interface was not found regardless of annealing times. As shown in Fig. 7 obtained from EDS analysis, composition gradients were observed through the interface area. Interestingly, the thicknesses of intermetallic layer were measured as 4.8, 7.2, and 3.0μm from Figs. 7 (a), (b), and (c), respectively, which is presumably caused by the grain growth rate affected formation rate of the intermetallic layer.

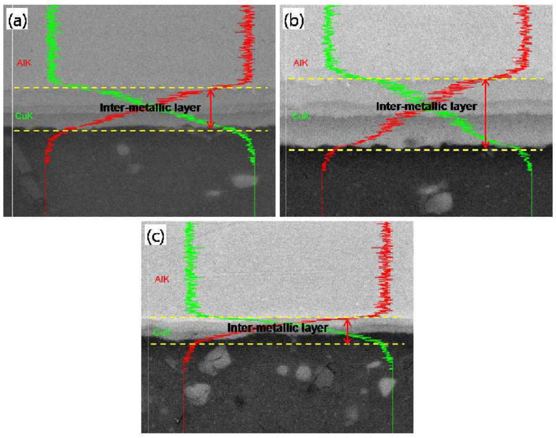

Fig. 7 Composition gradients through interface area obtained by EDS analysis on the specimens of cladded sheet obtained at 100°C under the speed ratio of 2:1 with thickness reductions of 45% followed by annealing at 400°C for 30 (a), and 60 (b), and 120min (c), respectively

Fig. 8 shows tensile test results conducted on the raw materials and cladded sheets obtained under various conditions. By post annealing heat treatment, tensile elongation of cladded sheets were dramatically increased with tensile strengths in the range comparable to Al 3003 raw material.

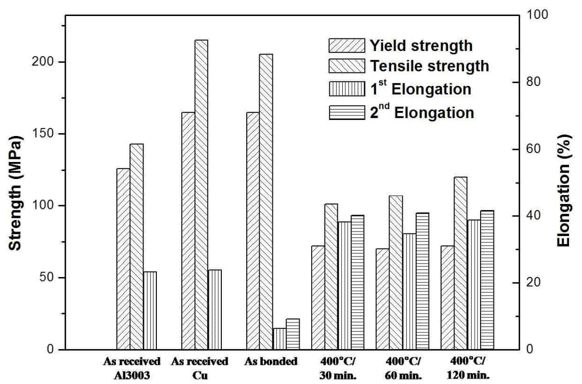

Fig. 8 Tensile test results conducted on raw materials, as-cladded sheets, and annealed at 400°C for various times

IV. Conclusions

In the present study, Al/Cu clad sheets were successfully fabricated by differential speed rolling at 100°C under the speed ratio of 2:1 with various thickness reductions up to 45%. Any void or crack could not be observed and there exist compositional gradients in the interface area. The thicknesses of intermetallic layer measured were increased up to 7.2μm with increased annealing time until 60min and decreased for longer annealing time, which is presumably caused by the grain growth rate affected formation rate of the intermetallic layer. By post annealing heat treatment, tensile elongation of cladded sheets were dramatically increased with tensile strengths in the range comparable to Al 3003 alloy.

Acknowledgment

This research was financially supported by the the Ministry of Education, Science and Technology (MEST), Gangwon Province, Gangneung City, Gangneung Science Industry Foundation (GSIF) as the R&D Project for Gangneung science park program.

References

[1] Y.-M. Hwang and G-Y Tzou, Int. J. Mech. Sci., vol. 39, pp. 289-303, 1997.
[2] H. D. Manesh, and A. K. Taheri, J. Alloys Compd., vol. 361, pp. 138-143, 2003.
[3] R. Jamaati and M. R. Toroghinejad, Mater. Des., vol. 31, pp. 4508-4513, 2010.
[4] L. Li, N. Nagaiand F. X. Yin,Sci. Tech. Adv. Mater., vol. 9, pp. 1-11, 2008.
[5] N. Bay, C. Clemensen, O. Juelstorp and T. Wanheim, CIRP Ann. Manuf. Tech., vol. 34, pp. 221-224, 1985.
[6] W. Zhang, and N. Bay, Weld. J., vol. 76, pp. s326-s330, 1997.