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Fabrication of Two Layers Al/Cu Metal Composite by Roll Bonding Technique

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ABSTRACT

The sheet metal of two-layer composite (Al/Cu) is considered as one of the most important products used in different engineering applications. The roll bonding technique (RBT) is an active process to fabricate the metal composite due to the occurrence of high deformation that leads to layers bonding together. In this study, Al8112 and pure Cu were selected as the metals to create a sheet composite (Al8112/Cu) by employing RBT on the basis of one cycle at various thickness reductions (R%; 45%, 50%, 55%, and 60%) and bonding temperatures (T; 350 °C, 400 °C, and 450 °C). The microstructure behaviour was examined to check the overlap bonding area for the composite layers. Vickers microhardness and tensile tests were also performed to measure the hardness, yield strength, and tensile strength. The results revealed that the R% had a strong effect on the interface bonding zone and hardness. It also had a significant effect on yield and tensile strength. On the other hand, T had a remarkable effect on the hardness and an important impact on the yield and tensile strength.

1. Introduction

The roll bonding technique (RBT (is one of the significant metal-forming procedures that could be considered a solid-state welding method that uses a rolling machine. The welding is performed on the basis of an atom-to-atom bond between contaminated free areas from two intimate contacted sheets [1]. Generally, multilayer plates including various metal layers are extensively utilized in industrial applications, such as parts for automotives and airplanes and electrical and thermal conductivities with high corrosion resistance and specific strength [2]. Al/Cu composite is one of the most important metals used in different electric and electronic applications and in automotive bodies, aerospace, and heat exchangers due to its very good features, such as lightweight, good corrosion resistance, high electrical and thermal conductivity and high plasticity [3-5]. RBT is considered a recent method in continuous manufacturing to produce sheet metals, including multilayers, at low cost [6]. It could be performed with and without heating for the initial metals representing hot and cold roll bonding (CRB), respectively. In the hot rolling technique, the different metals are compressed by rolls and the layers are overlapped in the contact area due to the plastic deformation that leads to weld occurrence. The interface bonding creates at a temperature lower than the crystallisation temperature. The bonding strength between layers is relatively important in the fabrication of sheet composites because is it subjected to further operations, such as bending, pressing, and cutting. The bonding strength generated by the rolling technique depends on various factors, such as

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thickness reduction (R%) through the process, rolling velocity, temperature, heat treatment, and particles containing reinforced particles from micrometre to nanometre scales [3,7]. The initial sheet surfaces were cleaned by degreasing and dusted using wire brushing to obtain a good bonding with high strength between composite layers and ensure a sufficient overlap of these layers [8]. Many researchers used RBT to produce metal composites and investigated their microstructure and mechanical properties. Reza Nasir et al. created an Al-Zn composite by using accumulative roll bonding (ARB), which refers to the multicycles for the roll bonding process. The results revealed that the strength, microhardness and elongation increased when the number of cycles for ARB was increased [8]. Roohollah et al. used CRB to produce AA1100 sheets to study the key variables influencing bond strength. They improved the bond strength at higher R%, lower beginning thickness and faster rolling speed [9]. A. H. Eslami et al. applied ARB to fabricate multi-layered Cu/Ni and examine the mechanical properties of the manufactured composites. They found that the increase in ARB passes resulted in an increase in the strength, microhardness and elongation [10]. Another study adopted ARB to fabricate Al/Al/12% Si composite on the basis of CRB to examine the microstructure and mechanical properties. The tensile strength reached 270 MPa at the first cycle and then it dropped, whereas the hardness increased when the ARB cycles were increased [11]. FatImantalabtah-alhosseini et al. conducted ARB for pure Cu to explore the microstructure, mechanical features, and strain hardening behaviour. The results showed that the grain size of the metal decreased with the increase in the number of process cycles. The yield and tensile strength were recorded to be 360 and 396 MPa, respectively, with ultrafine grained structure. Moreover, the strain hardening rate decreased after the third cycle of ARB [12]. J. Nie et al. applied ARB to fabricate Al/Mg/Al multi-layered composites employing four cycles at a constant temperature of 400 °C to examine the microstructure and bonding features for the interface zone. They revealed that there was important in the refining of grain size in Al and Mg layers and a significant increase in the ultimate strength at the third cycle [13]. In another study, a brass/steel/brass composite was produced at ambient temperature and an R% of 37%–72% provided the best strength joint between layers [14]. Mg-Li alloy was used to fabricate a three-layer composite including Al/Mg/Al on the basis of the CRB process. The microstructure and mechanical properties of the composite were tested. The increase in R% during the process demonstrated a significant effect on increasing the bond strength between layers [15-16]. B. Y. Zhang et al. examined the microstructure and mechanical properties of roll-bonded and annealed SUS304/Q235 multilayer steels by using an optical microscope. They showed that the hardness and tensile strength increased with the increase in rolling reduction ratio [17]. M. Sedighi et al. performed a warm ARB process to create Al metal matrix composites reinforced with alumina particles and studied the microstructure and mechanical properties of the composites. The results indicated that the strength and average microhardness of the ARB-processed material improved by increasing the volume percentage of the alumina particles [18]. Al/Cu/Mn composites were also created using ARB. As the ARB process progressed, the strength and microhardness of the generated composites increased with increasing strain on the structural and microstructural levels [19].

Based on the literature studies that were introduced above, ARB is widely applied. ARB means that the metal composite is created with a multicycle process for the roll bonding. Therefore, the fabrication of two-layer composite metals based on RBT by means of a single-cycle process is relatively important to reduce time and costs. Meanwhile, Al/Cu composite is used in wide industrial applications, such as electrics and electronics, so continuously investigating the microstructure and mechanical behaviour is necessary to improve the final composite product. In this paper, hot roll bonding was adopted to fabricate a sheet composite including pure Al (Al8112) and pure Cu. R% of 45%, 55%, and 60% and bonding temperatures (T) of 350 °C, 400 °C, and 450 °C were applied. The microstructure and mechanical features were studied in depth to elucidate the effect of R% and T during the process.

2. Chemical composition and mechanical features of materials used

The chemical composition for pure Al 8112 and Cu was analysed by a mobile metal analyser device at 23 °C and 60% humidity. The analysis depended on the principle of smelting, where the surface is cleaned well of dust and oxides. Table 1 reports the results of the chemical composition analysis for Al 8112 and pure Cu. The mechanical properties were also determined by tensile test using a tester device (WDW-200E). Table 2 presents the mechanical properties of Al 8112 and pure Cu.

Table 1: Chemical composition of Al8112 and pure Cu

Element	Si	Fe	Cu	Mn	Pb	Mg	Cr	Zn	Al
Al8112 wt%	0.16	0.62	0.12	0.13	---	0.03	0.006	0.022	98.8
Pure Cu wt%	0.010	0.019	99.8	0.009	0.004	---	0.007	0.021	0.007

Table 2: Mechanical features of Al 8112 and pure Cu

Property	Al8112	pure Cu
Yield Strength	55.5 MPa	140 MPa
Tensile strength	124.2 MPa	360 MPa
Elongation%	25-26	49-55
Hardness	48 HV	60-70 HV
Melting point	493 - 671℃	809 - 1030℃

3. Experimental procedure of roll bonding technique RBT

Before the roll bonding process was started, the materials to be used were prepared. Al 8112 and Cu sheets were cut by a water jet machine with the dimensions of 100 mm long, 15 mm wide and 1 mm thick for each material. For a good bonding area, all the contamination layers, oxides, adsorbed ions, greases, moisture and dust particles from the sheets were removed using scratch brushing and a cleaner liquid, such as acetone, to maintain consistency amongst the samples. Welding was performed right after scratch brushing to avoid interference with bonding from oxidation. After the materials were prepared, the sheets were stacked and placed in a special laboratory oven for heating. Then, they were left for 30 min inside the oven at all T used (350 °C, 400 °C, and 450 °C). Figure 1a illustrates the RBT based on two layers for different metals. The rolling process was performed using a laboratory rolling device with a roll diameter of 55 mm and a roll width of 100 mm at a velocity of 3 m/min, as demonstrated in Figure 1b.

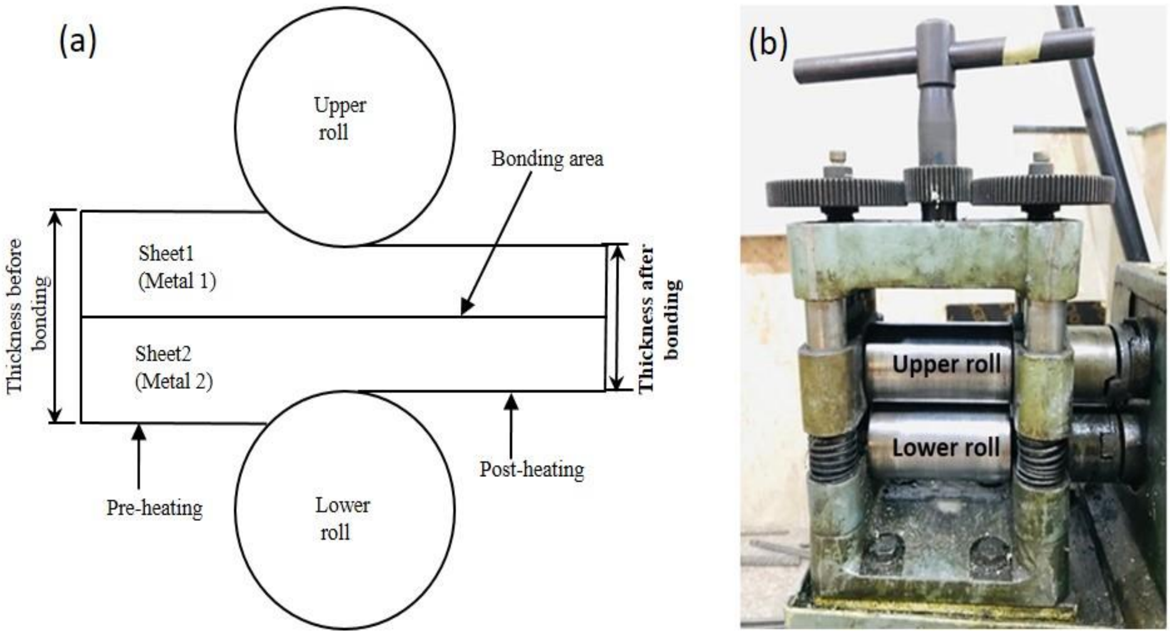

Figure 1. (a) schematic for RBT of different metals and (b) laboratory rolling device used for the RBT

Table 3 shows the roll bonding parameters applied in this work, including different T and R%. A very slight increase in the width of the sheet was found, hence neglected, and the width was considered a constant value of 15 mm before and after rolling.

Table 3: Roll bonding parameters and sheets dimensions

Roll bonding parameter		**Dimension before rolling**		**Dimension after rolling**	
Temperature (T) ℃	**Thickness reduction (R%)**	**Length mm**	**Thickness mm**	**Length mm**	**Thickness mm**
350, 400, 450	45%	100 mm	2 mm	181.18 mm	1.10 mm
	50%	100 mm	2 mm	200 mm	1 mm
	55%	100 mm	2mm	222.22 mm	0.9 mm
	60%	100 mm	2mm	250 mm	0.8 mm

4. Microstructure and mechanical features tests

Microstructure test was utilised to determine the roll bonding zone of the overlapped layers for Al8112 and Cu by using an optical microscope, as presented in Figure 2. Before the test was performed, the sample was prepared through grinding and polishing to obtain a smooth surface bonding. Then, a special etching solution was prepared, consisting of 94% water, 2.5% HNO, 1.5% HCL and 1.0% HF. This solution was used to show the microstructure and the area of overlap between the two metals. Finally, the sample was ready for examination and placed in its designated place at the device (Figure 2).

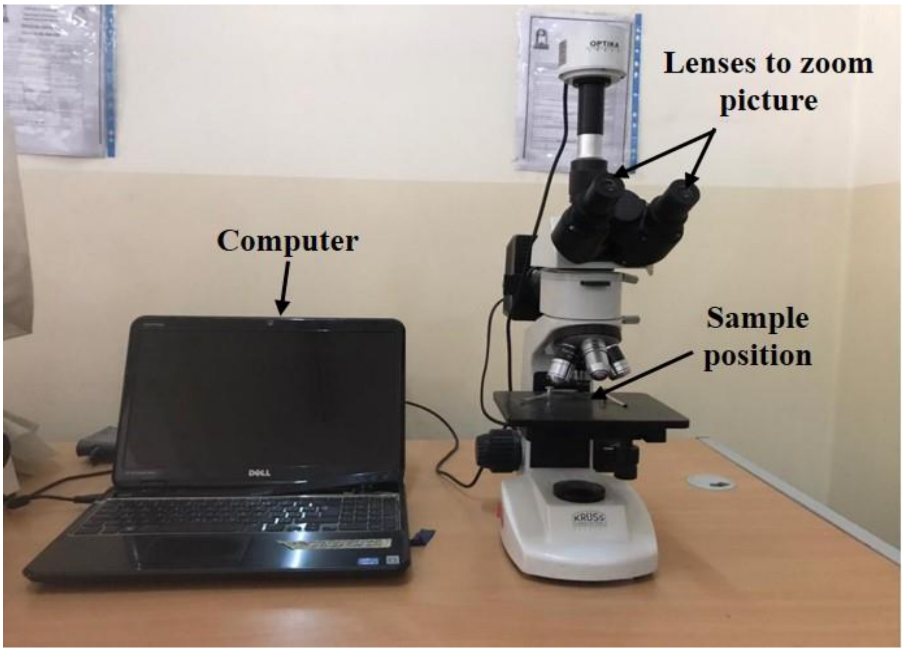

Figure 2. Optical microscope device

Hardness test was conducted to predict the Vickers microhardness of the composite metals (Al8211/Cu) produced by RBT. A part of the sheet composite was cut by a mounting machine, ground and polished to show the area where the hardness could be checked (cross-section) using grades 400, 600, 1000, 1200, and 2000 sandpaper. After the sample was prepared, it was placed in the appropriate position in the hardness device (Vickers microhardness model TH715) to perform the examination. Tensile test was performed to identify the yield and tensile strength of the Al8112/Cu composite at ambient temperature by using a tester device (WDW-200E) with a capacity of 20 tons and a tensile speed of 20 mm/min. All dimensions of the tensile sample were prepared in accordance with ASTM A370 standards, as shown in Figure 3.

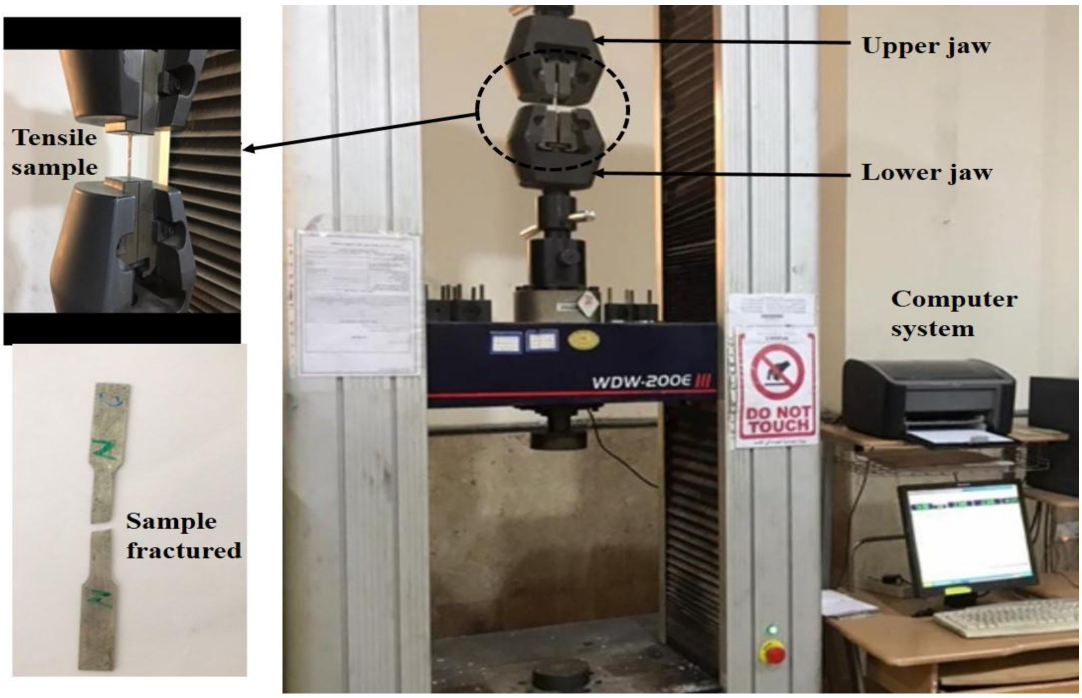

Figure 3. Tensile test setup

5. Results and discussions

5.1 Overlapping the microstructure of the layers of the Al 8112/Cu composite

Microstructure observations on a cross-section perpendicular to the rolling direction of the rolled samples were performed by optical microscopy (OM) at different R% and T. Figure 4 shows the microstructure of the cross-sections perpendicular to the rolling direction in the Al 8112/Cu composite after a single pass of the hot roll process. The interface zone of the Al/Cu composite was enhanced with the increase in R%. As shown in Figure 4, the R% of 60% demonstrated the best overlap of the composite layers for Al and Cu. The R% significantly affected the overlapped area for the Al 8112/Cu composite (when the R% increased, the interference correlation of the layers increased).

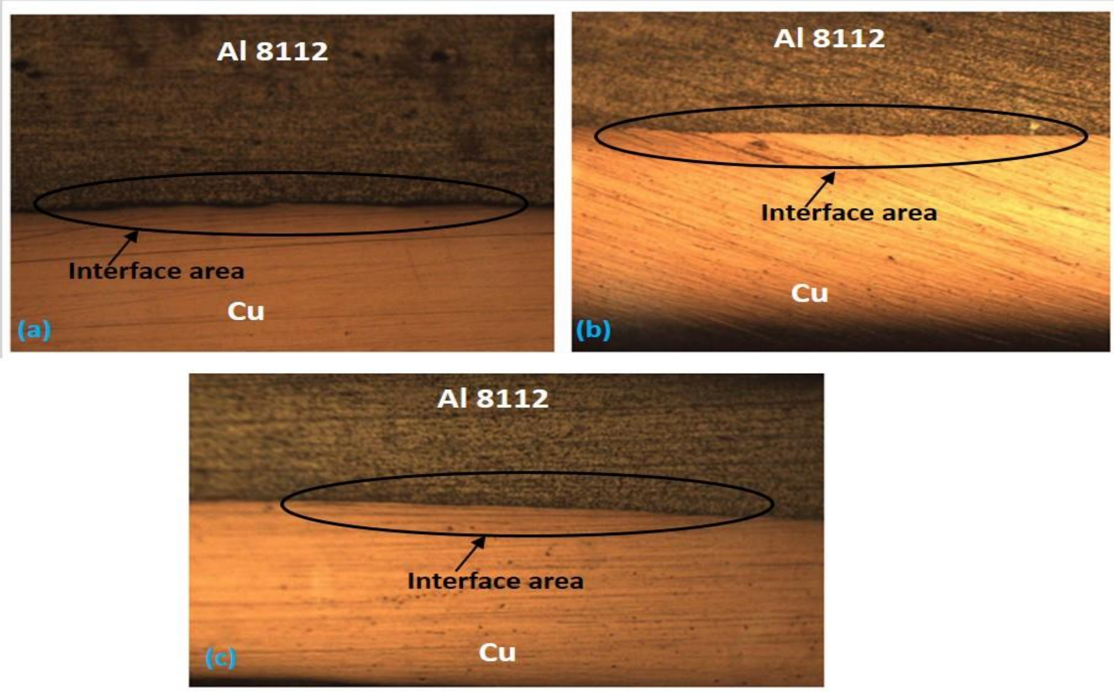

Figure 4. The microstructure behavior of Al 8112/Cu composite (a) R=45% and T= 400°C, (b) R=55% and T= 350°C, and (c) R=60% and T= 450°C

5.2 Results of Micro-Vickers hardness

The microhardness of the two-layer Al 18112/Cu metal composites was measured using a Vickers type (HV) in an overlapped area at more than one point and then the reading was recorded as an average value. Figure 5 presents the relationship between the Vickers microhardness (HV) and R% at various T. A direct relationship could be found between HV and R% for all T. The effect of R% on the hardness was directly proportional due to the increase in the waistline, leading to an increase in the hardness of the metal to increase the bonding and adhesion strength between the two metals. By contrast, T had an effect on the hardness of the metal composite so the change in hardness was close and slight in some points due to the effect of T. At 350 °C, a gradual increase in the hardness was observed until it reached the highest point at 73.1 HV. The hardness values of 69.2 and 63 HV were the highest values at 400 °C and 450 °C, respectively. The effect of T on the hardness was due to the principle of the thermal cycle. When the sample is heated and then cooled in the air, this process gives the metal a surface hardness.

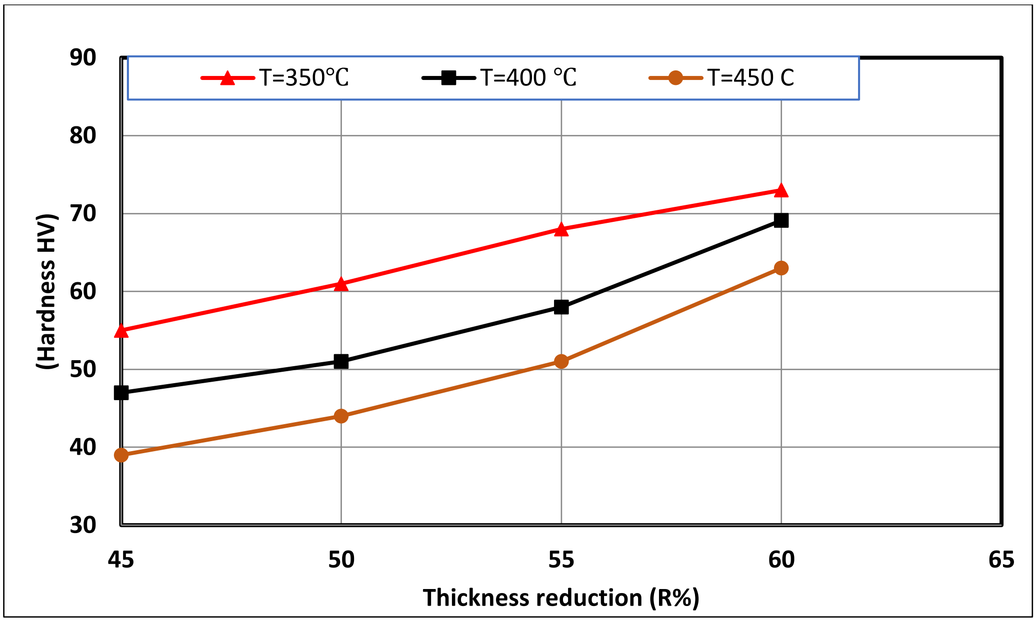

Figure 5. Thickness reduction (R%) vs micro-Vickers hardness (HV) at various roll bonding temperatures (T)

5.3 Results of yield point and tensile strength

Figures 6 and 7 illustrate the relationship between R% and yield point and R% versus tensile strength, respectively, for the Al 8112/Cu sheet composite at various T. According to Figure 6, the yield strength increased when the R% increased. At 350 °C, 400 °C, and 450 °C, with an increase in R%, the highest values of yield strength were 120, about 116, and 107 MPa, respectively. The lowest T=350° had the highest effect on increasing the yield strength. These effects could be attributed to different reasons, including the combined effect of R% and T; the increased dislocation density induced on the sheet; and the fine grains of the structure, which could also enhance and increase the mechanical properties, such as tensile strength and hardness [20].

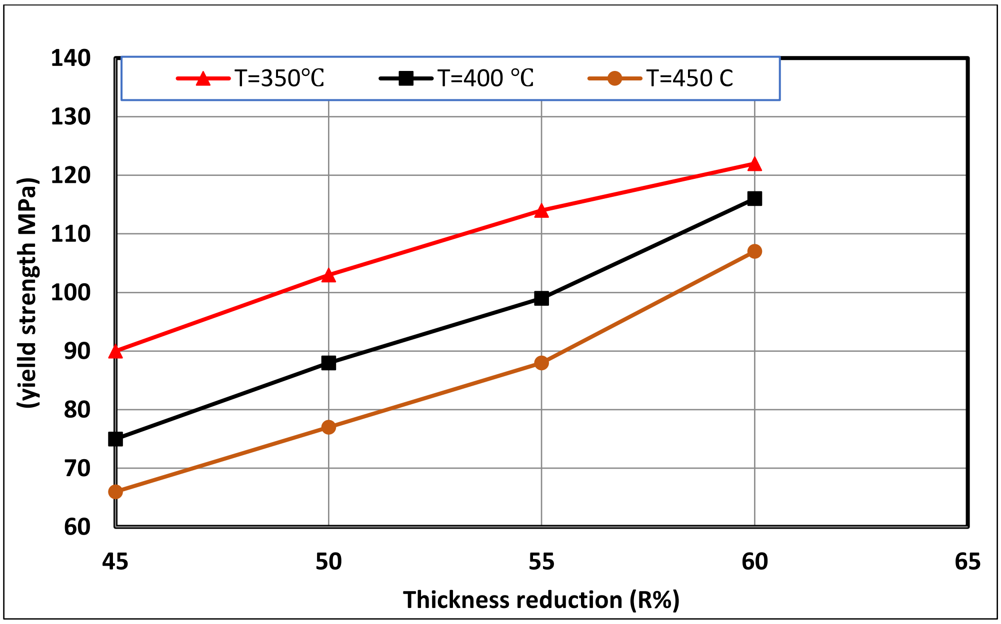

Figure 6. Thickness reduction (R%) vs yield strength at various roll bonding temperatures

As shown in Figure 7, the tensile strength of the composites increased with the increase in R%. At 350 °C, 400 °C, and 450 °C the highest values of tensile strength were 177, 170, and 160 MPa, respectively, under the same condition for the increase in R%. This finding was due to the smoothness of the inner grain size and the good inter-atomic bonding that led to the increase in the tensile strength with the increase in R%. When the temperature was increased to 450 °C, the tensile strength decreases due to the heating and the cooling in air.

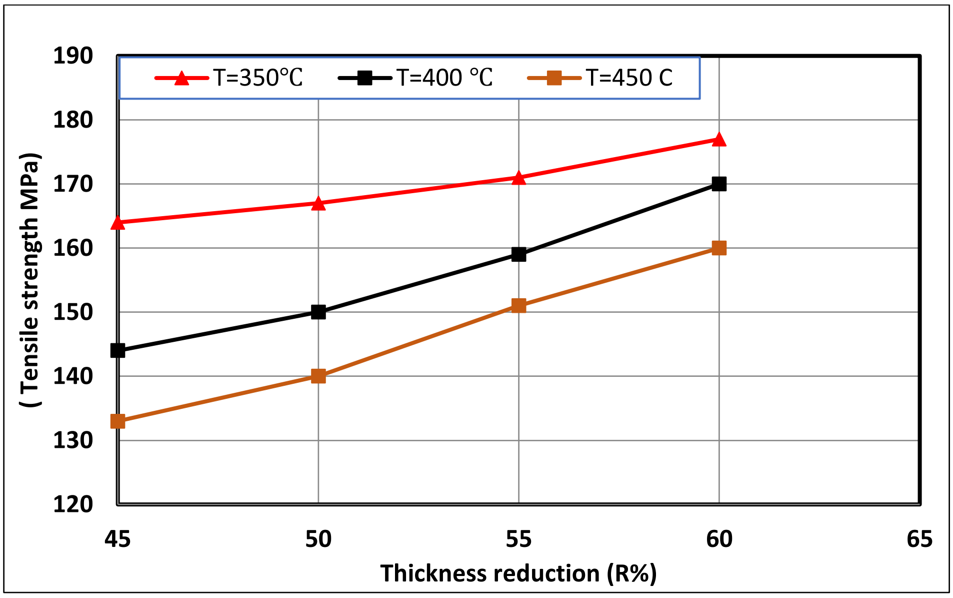

Figure 7. Thickness reduction (R%) vs tensile strength at various roll bonding temperatures

6. Conclusions

In this work, an Al-grade 8112/ pure Cu sheet composite was successfully fabricated using RBT with different R% of 45%, 50%, 55%, and 60% and various T of 350 °C, 400 °C, and 450 °C. Microstructure and mechanical tests were conducted to determine the interface composite layers, HV, yield strength, and tensile strength. The following points could be summarised as follows:

1. An overlapped bonding area could be obtained at various R% and T. The R% and T strongly affected the microstructure interface for the composite layers. The best results for R% and T were 60% and 450 °C, respectively.
2. HV increased when the R% increased for the different T. Meanwhile, a remarkable effect of T was found on HV.
3. The yield strength increased with the increase in R%. Also, an important effect of T was observed on yield strength.
4. The increase in T could lead to a decrease in tensile strength, whereas R% could increase it.

References

[1] M. Movahedi, A. H. Kokabi, and S. M. Seyed Reihani, "Investigation on the bond strength of Al-1100/St-12 roll bonded sheets, optimization and characterization", Mater. Des., vol. 32, no. 6, pp. 3143–3149, 2011, doi: 10.1016/j.matdes.2011.02.057.

[2] M. Vaseghi, H. Zand, and M. Sameezadeh, "Mechanical bonding in cold roll-cladding of tri-layered brass/steel/brass composite", Int. J. Mater. Res., vol. 111, no. 10, pp. 826–832, 2020, doi: 10.3139/146.111951.

[3] M. Naseri, M. Reihanian, and E. Borhani, "Bonding behavior during cold roll-cladding of tri-layered Al/brass/Al composite", J. Manuf. Process., vol. 24, pp. 125–137, 2016, doi: 10.1016/j.jmapro.2016.08.008.

[4] Y. Miyajima, K. Iguchi, S. Onaka, and M. Kato, "Effects of rolling reduction and strength of

composed layers on bond strength of pure copper and aluminum alloy clad sheets fabricated by cold roll bonding", Adv. Mater. Sci. Eng., vol. 2014, 2014, doi: 10.1155/2014/614821

[5] X. Wei, Y. Tomiko, and N. Kazumasa, "Formation of intermetallic compounds on the bond interface of aluminum-clad copper and its influence on bond tensile strength", Appl. Mech. Mater., vol. 117–119, pp984–989, 2012, doi: 10.4028/www.scientific.net/AMM.117-119.984

[6] R. Jamaati, M. Naseri, and M. R. Toroghinejad, "Wear behavior of nanostructured Al/Al2O3 composite fabricated via accumulative roll bonding (ARB) process", Mater. Des., vol. 59, pp. 540–549, 2014, doi: 10.1016/j.matdes.2014.03.027

[7] V. Yousefi Mehr, M. R. Toroghinejad, and A. Rezaeian, "The effects of oxide film and annealing treatment on the bond strength of Al-Cu strips in cold roll bonding process", Mater. Des., vol. 53, pp. 174–181, 2014, doi: 10.1016/j.matdes.2013.06.028.

[8] R. N. Dehsorkhi, F. Qods, and M. Tajally, "Investigation on microstructure and mechanical properties of Al-Zn composite during accumulative roll bonding (ARB) process", Mater. Sci. Eng. A, vol. 530, no. 1, pp. 63–72, 201.

[9] R. Jamaati and M. R. Toroghinejad, "Investigation of the parameters of the cold roll bonding (CRB) process", Mater. Sci. Eng. A, vol. 527, no. 9, pp. 2320–2326, 2010,

[10] A H. Eslami, S. Mojtaba Zebarjad, and M. M. Moshksar, "Study on mechanical and magnetic properties of Cu/Ni multilayer composite fabricated by accumulative roll bonding process", Mater. Sci. Technol. (United Kingdom), vol. 29, no. 8, pp. 1000–1005, 2013.

[11] N. El Mahallawy, A. Fathy, W. Abdelaziem, and M. Hassan, "Microstructure evolution and mechanical properties of Al/Al-12%Si multilayer processed by accumulative roll bonding (ARB)", Mater. Sci. & Eng. A, vol. 647, pp. 127-135, 2015, doi: 10.1016/j.msea.2015.08.064.

[12] FatImantalabtah-alhosseini, O., Y. Mazaheri, and M. K. Keshavarz, "Microstructural evolution, mechanical properties, and strain hardening behavior of ultrafine grained commercial pure copper during the accumulative roll bonding process", Mater. Sci. Eng. A, vol. 650, pp. 8–14, 2016, doi: 10.1016/j.msea.2015.10.043.

[13] J. Nie et al., "Fabrication of Al/Mg/Al composites via accumulative roll bonding and their mechanical properties", Materials (Basel)., vol. 9, no. 11, 2016, doi: 10.3390/ma9110951.

[14] M. AVseghi, H. Zand, and M. Sameezadeh, "Mechanical bonding in cold roll-cladding of tri-layered brass/steel/brass composite", Int. J. Mater. Res., vol. 111, no. 10, pp. 826–832, 2020, doi: 10.3139/146.111951.

[15] D. Rahmatabadi, M. Pahlavani, and J. Marzbanrad, "Manufacturing of three-layered sandwich composite of AA1050 / LZ91 / AA1050 using cold roll bonding process", J. Eng. Manuf. Pp. 1-10, 2021, doi: 10.1177/0954405421995667.

[16] D. Rahmatabadi et al., "Experimental investigation of formability of Al / Mg / Al strips fabricated via cold roll bonding process", Proceedings of Iran International Aluminium Conference (IIAC2018) April 24-25, 2018, Tehran, I.R. Iran.

[17] B. Y. Zhang et al., "Microstructure and mechanical properties of SUS304/Q235 multilayer steels fabricated by roll bonding and annealing," Mater. Sci. Eng. A, vol. 740–741, pp. 92–107, 2019, doi: 10.1016/j.msea.2018.10.054.

[18] M. Sedighi, M. Heydari Vini, and P. Farhadipour, "Effect of alumina content on the mechanical properties of AA5083/Al2O3 composites fabricated by warm accumulative roll bonding", Powder Metall. Met. Ceram., vol. 55, no. 7–8, pp. 413–418, 2016, doi: 10.1007/s11106-016-9821-0.

[19] Y. Miyajima, K. Iguchi, S. Onaka, and M. Kato, "Effects of rolling reduction and strength of composed layers on bond strength of pure copper and aluminum alloy clad sheets fabricated by cold roll bonding", Adv. Mater. Sci. Eng., vol. 2014, 2014, doi: 10.1155/2014/614821.

[20] M. D. Gholami, R. Hashemi, and M. Sedighi, "The effect of temperature on the mechanical properties and forming limit diagram of aluminum strips fabricated by accumulative roll bonding process," J. Mater. Res. Technol., vol. 9, no. 2, pp. 1831–1846, 2020.