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دراسة البنية المجهرية والخواص الميكانيكية لمركب المنيوم/ نحاس متعدد الطبقات المصنوع بواسطة عملية الدرفلة

رسالة مقدمة الى

مجلس كلية الهندسة / جامعة ديالى

وهي جزء من متطلبات نيل درجة الماجستير في علوم هندسة المواد

من قبل

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١٤٤٤ هـ **٢٠٢٣م**

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Microstructure and Mechanical Properties Investigation of a Multilayered Aluminum /Copper Composite Fabricated By Roll Bonding Process

A Thesis Submitted to Council of College of Engineering, the University of Diyala in Partial Fulfillment of the requirements for the Degree of Master of Science in Material Engineering

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2023A.D **1444H**

Chapter One

Introduction

1.1 Background

The extensive applications of the multilayered metal composite led to an increase in the number of studies for the Roll Bonding Process (RBP) that can consider an active technique with low cost. Metal composites by means of similar and dissimilar types that include two or more metals consider significant products utilized in mechanical and electrical uses [1]. Many techniques including squeeze stir casting, spray forming, and powder metallurgy are employed to create metal composites. On the other side, there are many problems that occur during these techniques such as nonuniform distribution and agglomeration as well as poor wettability leading to a decrease in mechanical and electrical characteristics [2]. Due to the expensive machinery and complicated processing procedures needed for the aforementioned technologies, the price of producing (MC) is considerable, which limits the uses for MC material [2]. SPD which is an abbreviation for severe plastic deformation represents the comprehensive term for metal manufacturing like axisymmetric rolling, equal channel angular extrusion, straightening etc. applied to create grain size with ultrafine reaches to 50%. Experimental procedures such as roll and Accumulative Bonding (ARB) were adopted based on the rolling process [3].

1.2 Roll Bonding Process (RBP)

RBP is the solid-state bonding technique in which polluted free regions from two closely-contact sheets form an atom-to-atom bond. During the bonding process, the layers of the materials start to move to each other, and the surface expansion overlaps due to the effect of roll pressure. The material is passed during the cracks for the broken oxide [4]. The roll bonding process is one of the most efficient and affordable ways to produce metals composite compared to hot dipping and explosive welding [5]. Before the bonding, the sheet surfaces are subjected to treatments, like cleaning with acetone and removing degreases by brushing to ensure a strong attaching [6]. Cutting the plates to the required length and width according to the prescribed procedure is done using one of the available cutting techniques, such as cutting with water, wire, or a saw. The sample is next purified to remove impurities in order to get the best bonding possible because contaminants impair the bonding between the plates. The metals which to be bonded together undergo several runs or passes to achieve the best correlation; the cleaner the surface, the more frequently a favorable correlation happened [7]. In comparison to a single strip layer, a multilayer strip's plastic deformation mechanism is more complicated due to variations in different physical characteristics, such as the thickness of the layers, and mechanical features, such as yield strength [8,9]. For the production of similar and dissimilar layered composites, such as Al, steel, Cu, Al-Ti, Al-Mg, Al-Zn, and Al-steel, the roll bonding procedure (cold and hot) has been widely employed [10].

1.3 Type of Roll Bonding Process (RBP)

The roll bonding process can be divided into two types based on the used temperature as follows:

1.3.1 Hot Roll Bonding (HRB)

The Hot Roll Bonding (HRB) includes heating of the metal above the temperature of recrystallization between (0.5 Tm to 0.75Tm). The heating process should be prepared just before rolling to make the metals more ductile and strengthen the link between them [11]. The processes of hot rolling process begin with the sample being prepared, which involves cutting and cleaning, and then using special furnace for the heating process. In this type, there is the most important advantage represented in the ease of overlapping between layers of the metals. On the contrary, there is a disadvantage represented in oxidation in a non-protective atmosphere and low bond strength when metal interfaces are oxidized [12]. The Hot Roll Bonding (HRB) method has lately been widely used in a range of industries due to its capacity to create a huge area of bimetals at high temperatures. The HRB process, in particular, offers advantages such as cost savings and increased mechanical strength, and resilience to heat and corrosion when joining dissimilar metals [13].

1.3.2 Cold Roll Bonding (CRB)

Cold Roll Bonding (CRB) occurs at or just above room temperature. When the oxide layers are split up by surface expansion and the surfaces are joined by rolling pressure, a type of solid-phase bonding process is used. In this type, the bonding of the layers takes place due to the plastic deformation produced by the effect of the rolling operation [14]. Superior surface quality for the composite can be obtained with uniform layers and there is no surface (internal) which are the major characteristics of this type of rolling mill. The Cold Roll Bonding (CRB) is applied with high pressure at a thickness reduction of 60% to fabricate two metal composites as well as heat treatment is required in terms of the post-rolling annealing for the metallurgical bond [12].

1.4 Factors Affecting the Rolling Process

Many factors affect the rolling process, which are explained as follows [15]:

1.4.1. Reduction Thickness (%)

The most important characteristic is the thickness change following the RBP application.

1.4.2 Surface Preparation

The majority of material surfaces have various oxide layers and impurities that have been absorbed, preventing robust bonding. Surface preparation conditions are crucial factors as a result.

1.4.3 Heat Treatment

The application of heat to roll-bonded samples can be further broken down into pre-, inter, and post-processes. It is possible to improve the mechanical characteristics of the sample after rolling by applying heat treatments, which has a substantial impact on the sample's properties, especially after rolling.

1.4.4 Rolling Speed

The mechanical characteristics, microstructure, and joint interface can all be impacted by rolling speed , which is undoubtedly one of the most important process variables. Rolling speed affects the process in two ways. High temperatures can be caused by fast rolling. They are beneficial for a strong joint quality, but they also compromise the time needed to allow for adequate bonding.

1.4.5 Rolling Temperature

The process of rolling is impacted by the temperature, which is a significant element used for the rolling operation. The type of rolling technique, such as hot rolling or cold rolling, affects the qualities of the sample after rolling, regardless of whether the temperature is high, medium, or low.

1.5 Layers Number of the Metal Composite

The roll bonding process can be applied in various numbers of layers:

1.5.1 Two Layer Roll Boding

Two metals are used and deformed together using the rolling process as shown in figure 1.1. Different metals are used to obtain metal composites containing two layers, such as Al/Cu [10], AA5083/Al2O3 [16], AA1060/TiO2 [17], and Cu/Ni [18] and Al/Ni [10, 16-17, 18-19].

1.5.2 Three Layers Roll Bonding or More

Three layers or more are used to obtain to final metal composite using a rolling process. For example, Al-Mg-SC, brass/steel/brass, Al-Cu-Al2O3, Al/brass/Al, Al/Mg/Al, Ti/Cu/Ti or more like Ni/Ti/Al/Cu [20-26].

On the other hand, similar and dissimilar materials can be applied to produce multilayered composites, dissimilar like Al/steel multilayered composites [1]. Similar such as two-layer of aluminum strips [27].

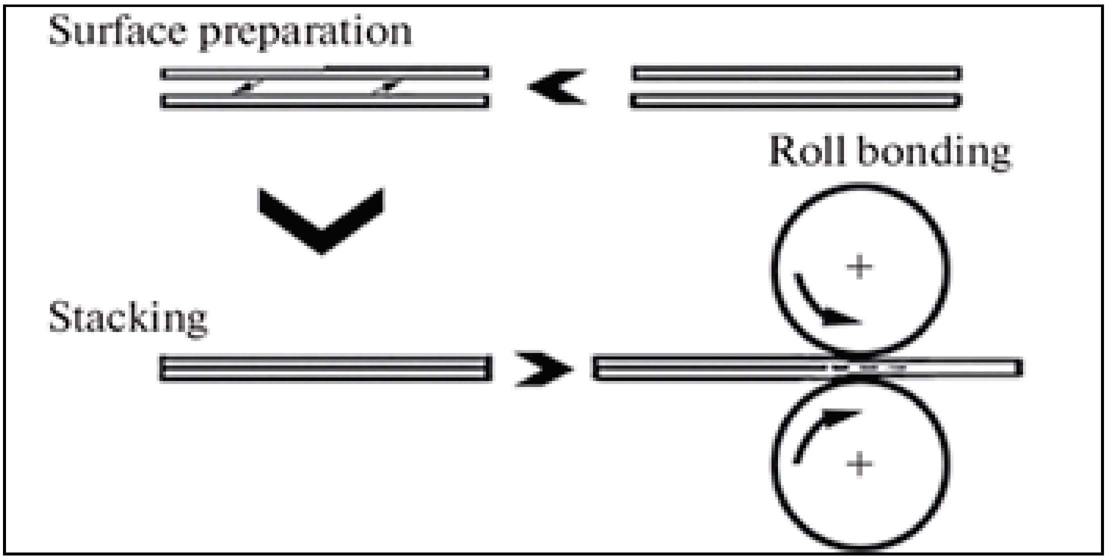

Figure 1.1 Roll bonding process [28].

1.6 Aluminum Alloys

In the early 1920s, aluminum alloys used to be an essential material instead of wood for the airframe. Aluminum is one of the easiest metals to make high-performance materials, which typically correlates directly with cheaper costs. In addition, heat treatment can be used to increase the strength of a relatively cheap, lightweight metal. [29]. Other qualities of economic significance include resilience to corrosion in natural environments, a high degree of electrical and thermal conductivity, high reflectivity, suitability for preserving food, beverages, and simplicity of recycling [30]. Alloys of aluminum are often divided two categories the figure below shows the most important classifications of aluminum.

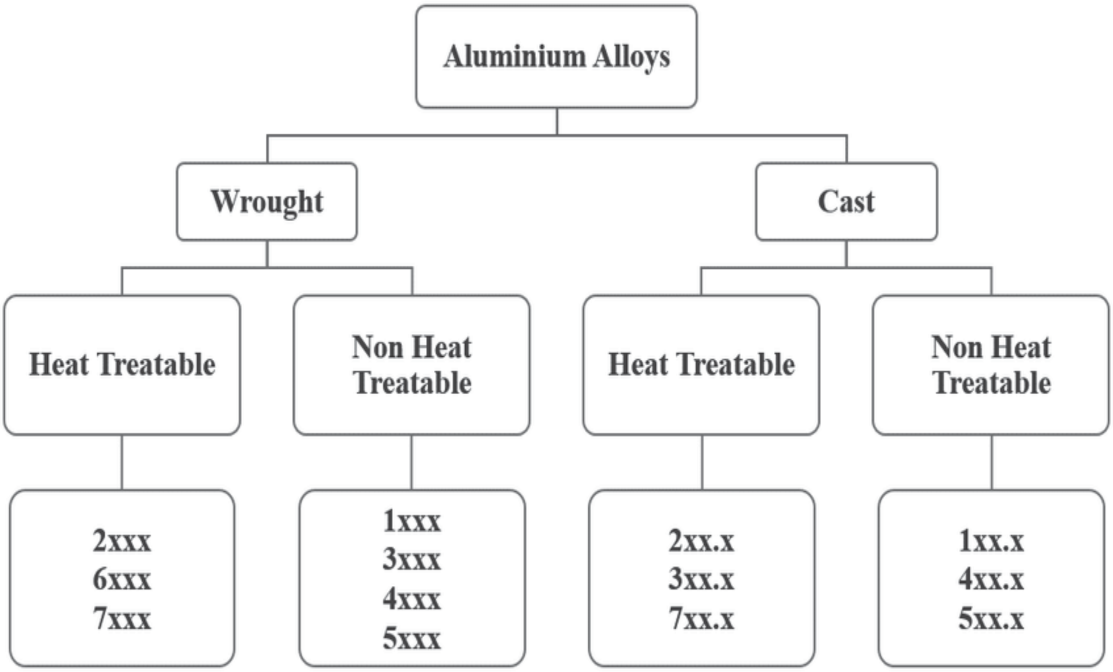

Figure 1.2 classifications of aluminum alloys [31]

One of aluminum's most valuable qualities is how easily it can be formed into any shape. It frequently competes well with less workable, less expensive materials. Any required thickness, even foil that is thinner than [32]. 8XXX was used in this study because of its advantages 8000 has a higher strength-to-weight ratio than an equal ampacity copper wire. Since it is lighter, the pulling tension is lower [33]. One of the most important and prominent applications of this alloy Building Wires, Underground Cables, Service Cables, Braided cable etc. [34]. Some key characteristics of grade 8xxx alloys are: [35].

- High strength with good stiffness
- Superior electrical conductivity
- Excellent weight-to-strength ratio
- Improved resistance to creep
- Moderate-level stress relaxation
- Lower termination performance

1.7 Copper Alloy

Copper is a chemical element with the (Cu) It is a soft, malleable, and ductile metal with very high thermal and electrical conductivity. A freshly exposed surface of pure copper has a pinkish-orange color. Copper is used as a conductor of heat and electricity, as a building material, and as a constituent of various metal alloys, such as sterling silver used in jewelry, cupronickel used to make marine hardware and coins, and constantan used in strain gauges and thermocouples for temperature measurement [36 ,37]. Many copper alloys that have been developed have significant applications. A copper and zinc alloy is called brass. Typically, the term "bronze" refers to copper-tin alloys, but it can also apply to any copper alloy, such as aluminum bronze [36]. When the total impurities reach above 0.7%, the commercial of pure copper has high ductility and softly. These alloys are utilized for their simplicity of usage, electrical and thermal conductivity, corrosion resistance, appearance, and color. They are the most ductile, easiest to braze, and most commonly easiest to weld of all the engineering metals. Common uses include pipes for water, air, and process equipment, bars, heat exchangers, electrical wiring and fittings, roofing, and wall cladding. Electrical wire (60%), roofing and plumbing (20%), and industrial machinery (15%) are the three main uses of copper. When more hardness is required, copper is added to alloys like brass and bronze (5% of all uses), but it is also used as a pure metal [38].

1.8 Aims and Objectives of the Study

Layered composite metals have become an increasingly interesting topic in industrial development due to their unique service performance features**.** Multilayered materials can provide a wide range of applications. The weight of the multilayer Al 8112/ pure Copper is reduced compared to the conventional Cu plates. Another application of metal laminate is corrosion resistance applications. Two and three-layer composite is conducted in the present study by using a hot roll bonding process and investigation of the microstructure and mechanical properties. The aim and objectives of the study are:

- Producing a metal composite consisting two and three layers (Al8112 /pure Cu) and (Al8112/Cu/Al8112) using hot roll bonding process with different thickness reduction and roll bonding temperatures.
- Study the effect of thickness reduction and roll bonding temperature on the microstructure based on overlap area involving two and three layers respectively.
- Study the effect of thickness reduction and roll bonding temperature on the mechanical properties (hardness, yield strength, and tensile strength) of multilayers aluminum/copper composite of the two and three layers.

1.12 Outline of The Thesis

- ❖ Chapter one general introduction to the roll bonding process, the parameters of the process, the type of roll bonding, and the number of layers that can be applied in the roll bonding process.
- ❖ Chapter two presents a literature review of recently published papers and research progress about the investigation of the microstructure

and mechanical properties of multilayer composite fabricated by the roll bonding process.

- ❖ Chapter three introduces the experimental procedure of the roll bonding technique (RBP), the materials used in this study, and explain the device that was used.
- ❖ Chapter four shows the results of the roll bonding process with microstructure and mechanical tests including all graphs and figures, the results of the validation of previous research, and the results of the study.
- ❖ Chapter five gives the conclusions and recommendations by summarizing the main findings, and proposals for possible future work are also examined.

The roll bonding process is one of the widest methods used to produce sheet metal composite with similar and dissimilar materials. Composite metals produced by the rolling process are quite important because of their extensive applications in various engineering fields. In this thesis, hot roll bonding was applied to produce composite metals, where it was used in two cases. The first was the hot rolling procedure to fabricate composite sheets consisting of two layers, Al8112 /pure Cu. The second case represented the production of composite sheets including of three layers Al8112/pure Cu/Al8112. Different thickness reductions (45, 50, 55 and 60%) and roll bonding temperatures (300°C, 350°C, 400°C, and 450°C) were applied. The effect of thickness reduction and roll bonding temperatures on the microstructure and mechanical properties were checked. Microstructure evaluations and the mechanical properties, measure the hardness of two layer and three layers. The tensile test to find some mechanical characteristics such as yield strength and tensile strength was performed. The best results of the overlap zone were recorded at 60% and 450°C for both the two and three layers. The hardness increases when the thickness reduction R% increases at different roll bonding temperatures. Meanwhile, a remarkable effect of roll bonding temperature T was found on Vickers hardness HV at the thickness reduction R=60% and roll bonding temperature T=300°C. The results of hardness recorded 78HV and 95 HV in two and three layers respectively. The study showed that the yield strength increases when the thickness reduction (R%) augments and roll bonding temperature (T) reduces. At high thickness reduction and low roll bonding temperature, the yield strength was 130 MPa and 188 MPa two and three layers respectively. The increase in rolling thickness reduction led to a raise in tensile strength, while the augment in roll-bonding temperature could reduce tensile strength. At two layers the tensile strength was 191 MPa for thickness reduction R=60% and roll

bonding temperature T= 300°C while the yield strength of three layers was found 200 MPa at the same condition of two layer.