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An investigation into the effect of surface preparation method and heat Treatment on mechanical properties of multilayer Al / Al / Steel sheet produced by cold roll bonding

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Abstract

Existence of several parameters affecting the mechanical properties and bond strength of multilayer sheets produced by cold roll bonding have made research in this field necessary. In this paper, using the experimental method, the effect of several effective parameters such as temperature and time of thermal operation and type of sheet surface preparation on the mechanical properties of AA5456 / AA1020 / St321 three-layer sheet produced by cold rolling has been investigated. In this regard, two sanding methods, including flap disc and Cylindrical Sandpaper, have been used to prepare the surface of the sheets and heat treatment has been performed at three temperature levels of 310, 355, and 400 ° C for three periods of 30, 60 and 90 minutes. These tests showed that the highest increase in tensile strength was obtained in the sample of heat treatment at a temperature of 400 ° C for 60 minutes and surface preparation by Cylindrical Sandpaper.

Keywords: Cold roll bonding, Sandwich clad sheet, Aluminum / Aluminum / Steel, Mechanical properties, Tensile strength.

1. Introduction

Adopting novel materials with superior features and characteristics is necessary to keep up with the development of industry and technology in many domains. Metal composite materials, particularly multilayer metal components, are made of two or more metals, including novel materials that have recently attracted much interest and are used more often in high-tech sectors.

Significant sectors, including aerospace, airplanes, automobiles, and shipbuilding, employ composite metal materials extensively. Multilayer metal sheets have so far been created using sheets made of many materials, including aluminum, magnesium, zinc, titanium, steel, silver, and copper[1-4].

A three-layer sheet made of aluminum, aluminum, and steel has shown excellent qualities in the meanwhile. This sheet is lightweight, has excellent mechanical characteristics, and is very corrosion-resistant[5,6].

Several techniques have been developed to fabricate metal multilayer composite materials and join metal multilayers with other materials. Still, Of these methods, the cold rolling process has taken on a unique significance[7,8].

Several factors, including surface preparation techniques, surface roughness and hardness, heat treatment before and after the operation, etc., influence the mechanical characteristics of the sheets in the cold rolling joining method, such as surface hardness, yield strength, and final strength[9,10]. These characteristics also have an impact on the strength of the connection between the sheets, in addition to their influence on the mechanical qualities[11,12].

Even though there have been numerous studies in recent years on multi-layered metal sheets produced by the cold rolling process and the variables that affect them, these studies are still ongoing because of the wide range of these variables and the variety in the raw materials used to create multi-layered metal sheets.

This study aims to use an experimental approach to examine how annealing time, annealing temperature, and surface preparation affect the mechanical characteristics of three-layer sheets made of AA5456/AA1020/St321 materials.

In reality, the research's innovation can be seen in producing the three-layer

AA5456/AA1020/St321 sheet employing cold rolling and a thickness reduction percentage of 50% compared to the original thickness and then examining the effects of the given parameters on the mechanical characteristics of this sheet.

In this study, three degrees of temperature, annealing time, and two sanding techniques a flap disc sander and cylindrical sandpaper are used to test the strength and hardness of the sheet. The other influencing factors are configured so the sheet has a strong connection. The best conditions are then introduced to maximize the strength and hardness of the surface, utilizing the findings from these experiments.

2. Methodology

In this study, the temperature variations and the duration of the heat treatment in three levels after the cold rolling stage are determined as continuous parameters of the experiment design. In contrast, the sanding procedure during the sheets' surface preparation is defined as a discrete parameter. Two techniques for layer surface preparation have been chosen using sanding equipment, including flap discs and cylindrical sanding. The temperature levels of 310, 355, and 400 degrees Celsius and durations of 30, 60, and 90 minutes were selected for the heat treatment's duration. Based on the technique used to prepare the surfaces of the layers, the tests are divided into two basic categories: 9 trials for the flap discs method and 9 trials for the cylindrical sander method, resulting in a total of 18 tests.

The surfaces of the layers need to be prepared for strength and proper connection between the sheets before the cold rolling process. Therefore, the samples are submerged in a hydrofluoric acid solution to clean the surface of any contaminants before being transferred to the cold rolling process.

The sheets were initially cut to dimensions of $30\,mm \times 150\,mm$, and after completing the initial processes, a hole was formed in the head of the sheets, and each layer was riveted to the previous three layers. This is done to secure the layers in place and provide a firm grip for the rolling rollers.

The thickness between the two rollers of the rolling machine is reduced by 50% in the next stage. The cold rolling joining operation is performed at ambient temperature with one rolling pass completed in less than two minutes after the surface preparation step of the sheets is finished.

Finally, the resulting undergoes another round of heat treatment. Temperature and annealing time were changeable input parameters for this heat treatment.

3. Discussion and Results

Vickers Hardness Testers were used to determine the hardness of AA5456 and St321 sheets, and it was discovered that heat treatment had decreased the hardness of both sheets. The heat treatment period was the factor that had the most impact on the hardness of the sheets. From the beginning until 60 minutes, both sheets' hardness diminishes quickly, but after that, it does so with a little slope. The St321 sheet's hardness decreased by around 7%, and the AA5456 sheet's by about 25% after 90 minutes.

The ASTM E8 standard was followed in preparing the sheets for the tensile test, and the uniaxial tensile test was conducted on them to determine the samples' yield strength. Since all of the samples were produced parallel to the direction of the sheet rolling for the uniaxial tensile test, the test results show the sheet's strength in that direction for all of the samples.

Figure 1 displays the changes in the strength of three-layer metal sheet samples during heat treatment at three different temperatures (310, 355, and 400 degrees Celsius) and a fixed thickness reduction of 50%.

When the uniaxial tensile test data are analyzed, it is shown that the yield strength improves initially and then gradually falls with an increase in heat treatment time. The reason for the improvement in the connection between the layers is the cause of the increase in initial yield strength. However, as the heat treatment time increases, the hard work put forth during the rolling process decreases, especially in the case of the aluminum layer, and the yield strength of the sheet decreases while flexibility increases.

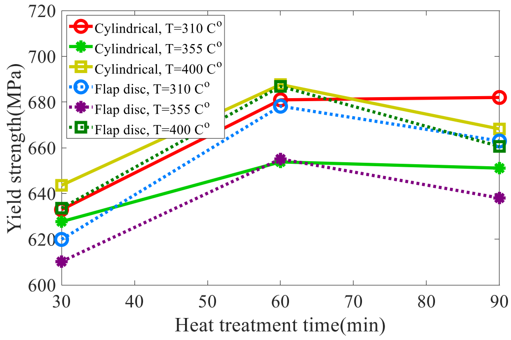

Figure 1. The impact of heat treatment duration on the yield strength of three-layer metal sheets prepared using cylindrical sanding and flap disc sanding techniques

According to this diagram, it can be seen that preparing the surface of the sheets with cylindrical sanding had a greater effect on increasing the yield strength of the sheet. This difference was more significant at 30 and 90 minutes for heat treatment and less at 60 minutes.

Strength diagrams in terms of temperature were created to explore the impact of increasing heat treatment temperature on yield strength. Figure 2 displays the strength alterations caused by heat treatment in three-layer metal sheet samples across 30 to 90 minutes, with a constant thickness decrease of 50%. According to Figure 2, the three-layer metal sheet's yield strength starts to fall at a temperature of 310°C and keeps declining until a temperature of 355°C. The strength decline stops when the strength reaches a temperature of 400°C, and strength rises at this temperature.

The striking difference between the samples heat treated at 400°C and 60 minutes compared with other heat treatment settings is evident from a comparison of the graphs in Figures 1 and 2. Additionally, samples of three-layer sheets made by cylindrical sanding show the most significant degree of strength.

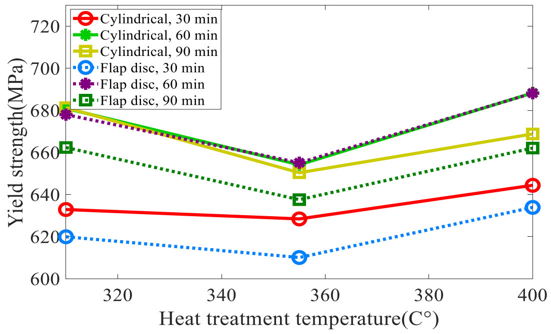

Figure 2. Effect of heat treatment temperature on the yield strength of three-layer metal sheet prepared with flap disc sanding and cylindrical sanding according to St321/AA1020/AA5456 standards.

The impact of the brittle layer formed at the layer interface during the surface preparation stage may be analysed to determine the effect of the surface preparation technique. Actually, by sanding operations, the surface of the sheets is hardened, and a brittle layer is generated on the sheet, and with the production of this brittle layer, the potential of atomic penetration rises, and as a consequence, resulting in an increase in strength.

Regarding heat treatment temperature, the hypothesis of atomic penetration at the interface and short-range atomic movements induced by heat may be related to increased strength following heat treatment at 400°C.

Figure 3 a, b displays the SEM picture of the longitudinal cross-section of the interface between the St321/AA1020 layers and cracks perpendicular to the sheet's rolling direction. This image shows that the brittle layer of St321 cracked, pierced, and spread the layer of AA1020 in the depth of the steel layer, resulting in the connection between the metal layers. In other words, extruded aluminum metal has created a mechanical lock at the junction of two metals. This phenomenon shows that due to the easier deformation of the aluminum layer, this metal is much easier to sink into the cracks of the steel layer, and the bonding agent has become more robust.

The rationale for getting the maximum level of strength in the surface preparation samples by cylindrical sanding is justified by comparing the photos in Figure 3 and evaluating the degree of opening and depth of the cracks generated at the junction of the two samples.

Figures 3c and d show the SEM images of the AA1020/AA5456 layer interaction. It is challenging to identify the connecting line by looking at the junction of the two layers of aluminum in this illustration. Two softer metals have been uniformly pressed together due to the cold rolling process. It seems that in reducing the thickness to the initial thickness of 50% for all three sheets, two aluminum sheets have experienced a more significant thickness reduction than the steel sheet due to being softer; for this reason, the actual contact surface of the two layers has increased and as a result, the possibility of penetration between the aluminum layers has also increased, which has led to a uniform connection between the two aluminum metals.

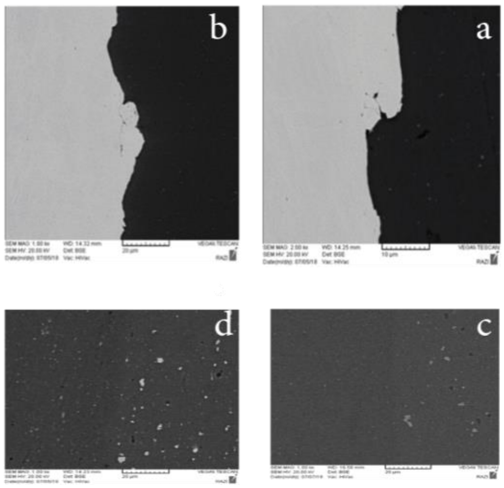

Figure 3. Scanning Electron Microscope (SEM) images of the longitudinal section of the interface between the layers of the AA1020 and St321 metal connection surface preparation under the methods of a) cylindrical sanding, b flap disc sanding and the interface of AA1020 and AA5456 layers surface preparation under the methods c) cylindrical sanding d) flap disc sanding

After the physical and chemical preparation of the surface of the sheets, the total initial thickness of the three-layer sheet before rolling was 4.2 mm. After rolling the sheet, its thickness reached 50% of the initial thickness, and the thickness of the obtained three-layer sheet was 2.1±0.1mm in different samples.

The percentage of thickness reduction in these three sheets, however, is not equal since the mechanical properties of the three sheets vary from one another, and in aluminum sheets, this percentage of thickness reduction is higher than that of steel sheets. The measurement of the changes in the thickness of the layers in the three-layer metal sheet shows that the maximum amount of thickness reduction due to the application of 50% reduction of the thickness to the initial thickness has occurred in the AA1020 layer by approximately 67%. Also, the lowest thickness reduction is related to the St321 steel layer, with a value of about 43%. The thickness changes in the AA5456 alloy layer also show a value of 55%.

The importance of an AA1020 layer with favorable mechanical characteristics as an interface layer in making a better connection is assessed by comparing the outcomes of thickness reduction in each layer.

4. Conclusions

The influence of a sheet surface preparation process, as well as the annealing time and temperature of the three-layer sheet with St321/AA1020/AA5456 material, on the surface hardness and yield strength of the resulting composite sheet was studied.

The results of these tests as well as the SEM images of the cross-section of the samples, show that:

1) The hardness of the AA5456 layer has increased by 47% compared to its initial hardness.
2) The hardness of the St321 layer has increased by 125% compared to its initial hardness.
3) At constant heat treatment temperature, increasing heat treatment time increased yield strength initially, and continuing this process decreased yield strength. Furthermore, during the constant heat treatment, the yield strength decreased and then increased as the temperature increased.
4) In terms of enhancing sheet yield strength, the cylindrical sander outperforms the flap disc sander in the physical preparation of the sheet surface.
5) Samples heat treated at 400°C for 60 minutes and prepared by cylindrical sanding showed the most considerable improvement in yield strength value.
6) The SEM pictures acquired from the cross-section of the samples show that the St321 layer has cracked, which is the source of aluminum metal penetration in the fissures of the steel layer, and it has produced a link between the metal layers by producing a mechanical lock.

5. References

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