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Deformation behavior, evolution of strain states and textures during roll cladding of five ply composite sheets

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Abstract

Two clad composites of five ply sheets comprising STS430/AA3003/AA3003/AA3003/STS430 and STS430/AA3003/STS430/AA3003/STS430 were produced by roll cladding at 350℃. In order to clarify the deformation behavior and strain states in the composites during roll cladding, the variation of individual sheet thickness and the evolution of through thickness textures and microstructures of the composites were investigated. The thickness reduction of each sheet depended on the location of the sheet and on the strength of each sheet in the composites. In order to elucidate the evolution of textures and microstructures in AA3003 sheets, the strain states in AA3003 sheets during roll cladding were calculated by FEM. The formation of shear textures and fine grains in AA3003 sheet was discussed in terms of the strain states in each sheet layer. Finally, the strain states extracted from the FEM were verified by texture simulations

Key Words : Five ply composite sheet, Rolling, Cladding, Strain, Texture. FEM

1. Introduction

In the present study, macroscopic thickness variations of composite sheets after roll-cladding of two assemblies of five ply sheets were measured to investigate the deformation behaviors of comprising sheets, and the strain states of aluminum sheets of the composites during roll-cladding were analyzed to investigate the effect of center positioned sheet on the evolution of textures and microstructures in the mid AA3003 sheet. For this purpose, two assemblies comprising STS430/AA3003/AA3003/AA3003/STS430 and STS430/AA3003/STS430/AA3003/STS430 were roll clad at an elevated temperature. The evolution of through thickness textures of the AA3003 sheets was characterized by X-ray texture analysis and corresponding strain states of AA3003 sheets during roll-cladding were obtained by finite element calculations. The evolution of textures in AA3003 sheets were discussed in terms of the variation of strain states, which were later used to simulate the evolution of textures of the AA3003 sheets.

2. Experimental Procedure

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The as received materials were commercial 0.488mm/1.0mm thick ferritic stainless steel (STS430) sheets and 1.0mm thick AA3003 sheet, respectively. Two different assemblies were prepared from those sheets . First, AA3003 sheet was sandwiched by AA3003 sheets, and then those stacked sheets were again sandwiched by 0.488mm thick STS430 sheets. Second, 1.0mm thick STS430 sheet was sandwiched by AA3003 sheets, and then those stacked sheets were again sandwiched by 0.488mm thick STS430 sheets. The front heads of these two assemblies were fixed by stapler. These two assemblies were heat treated at 350℃ for 20 minutes in order to anneal aluminum based alloy sheets (AA3003) and then inserted into roll gaps with a roll diameter of 470mm rotating at a roll speed of 0.4 rad/sec. The designed thickness reduction was 30%. In this work an assembly of STS430/AA3003/AA3003/AA3003/ STS430 roll clad at 350℃ is referred to sample A, and an assembly of STS430/AA3003/ STS430/AA3003/ STS430 roll clad at 350℃ is referred to sample B. The resulting thickness was measured at each sheet of sample A and sample B. The evolution of microstructures and textures of sample A and sample B was monitored by Electron Back Scattering Diffraction (EBSD) and X-ray texture analysis.

For texture analysis three incomplete pole figures were measured at different through thickness layers of sample A and sample B, including initial sample sheets, by means of conventional X-ray texture goniometer using Ni filtered Cu K radiation. From the three incomplete pole figures, the three-dimensional ODFs f(g) were calculated by the series expansion methods according to Bunge (*lmax*=22).

3. Experimental Results

3.1. Deformation behavior

The initial thickness of assemblies of STS430/AA3003/AA3003/AA3003/STS430 and STS430 /AA3003/STS430/AA3003/STS430 were 3.976mm. After roll cladding, measured thickness reduction was 22.0% in the sample A and 24.5% in the sample B, respectively. The outer STS430 sheets were hardly deformed, while the mid and center sheets were significantly deformed in the sample A and the sample B. It is notice worthy that the center AA3003 sheet was reduced in thickness slightly more than the mid AA3003 sheet in the sample A. The thickness reduction of the mid AA3003 sheet in the sample B was larger than that of the mid AA3003 sheet in the sample A as expected. In addition, the thickness reduction of the center STS430 sheet in the sample B was unexpectedly significant contrary to the slight thickness reduction of the outer STS430 sheet.

3.2 Evolution of Texture

Through thickness textures of initial AA3003 sheet are characterized by strong cube orientation with {001}//ND and by strong {011}<122> P orientation that can be observable in recrystallized aluminum alloys containing appreciable precipitates. Textures of initial AA3003 sample revealed that it was fully recrystallized. The through thickness textures of the mid AA3003 sheet in the sample A revealed that {001}<110> orientation and {111}<uvw> orientations prevailed at the upper surface (*s*=1) of the mid AA3003 sheet contacting with the outer STS430 sheet, while weak {001}<100> cube orientation and medium {011}<122> P orientation prevailed at the lower surface (*s*=-1) of the mid AA3003 sheet contacting with the center AA3003 sheet. The through thickness textures of the center AA3003 sheet in the sample A displayed a strong P orientation with a weak β-fiber at the surface layer (*s*=1) contacting with the mid AA3003 sheet and a pronounced β-fiber, which is a typical deformation texture under the plain strain condition, at the center layer (*s*=0) of the center AA3003 sheet. The textures of the mid AA3003 sheet of sample B revealed a strong {001}<110> orientation and pronounced {111}//ND orientations throughout the entire thickness layers.

4. Discusions

4. 1. Deformation behavior

The outer STS430 sheets were hardly deformed in the sample A and sample B. This phenomenon seems to be naturally accepted because roll pressure hardly build up in hard material during the deformation of soft material when hard material is stacked on soft material. The thickness reduction of the mid AA3003 sheet depended on the strength of the center material sheet. When the center material sheet has a higher strength than the mid layer material, the thickness reduction of the mid sheet is high compared with the case when the strength of the center material is similar with that of the mid material sheet. In this experiment, when the center material was STS430, the thickness reduction of the mid AA3003 sheet was 35%, which is equivalent to 0.423 in true strain, while, when the center material was AA3003, the thickness reduction of the mid AA3003 sheet was 26.5%, which is correspond to 0.308 in true strain. The thickness reduction in the center material sheet is more significant than the mid material sheet in the case when they are of the same material sheet. In this experiment, the center AA3003 sheet was reduced in thickness 2.3% more than the mid AA3003 sheet in the sample A. This phenomenon is consistent with the recent study of sandwich rollingof AA3003/AA3003/AA3003 assembly by authors. While the outer STS430 sheets deformed 5% in thickness, which correspondsto 0.054 in true strain, the center STS430 sheet in the sample B deformed 24%, which corresponds to 0.268 in true strain. Hence, it can be deduced that when a material sheet is located in the center, more significant thickness reduction can be obtained than when the material sheet is located in the outer. The deformation mechanism of STS430 sheet in the sample B can be explained by the deformation compatibility between AA3003 sheets and STS430 sheet. During build-up of pressure in the soft material corresponding to the yield strength of the soft material and deformation of the soft material in a roll gap, pressure in the hard material also increases up to the level of the yield strength of the hard material due to the deformation of the hard material induced by the deformation of the soft material. The variations of effective stresses acting on the mid AA3003 sheet and the center STS430 sheet during roll cladding of sample B were calculated by FEM. Since the effective stress of STS430 sheet reaches at the yield strength about 0.03 sec after roll entry and drops below the yield strength about 0.02 sec before the arrival of the roll exit, it can be understood that the deformation duration of the center STS430 sheet is 0.05 sec shorter than that of the mid AA3003 sheet, which support the deformation compatibility described above.

4.2. Evolution of strain states

The evolution of strain gradients during roll cladding was simulated with the commercial FEM package DEFORMTM-2D. In the present case of roll cladding, the shear factor was adopted since the friction coefficient could not be applicable. The shear factor *m* between roll and sheet or between sheet and sheet were assumed as 0.6 after a typical dry hot rolling range.

Since it is assumed that there is no deformation along the transverse direction of rolling, the stain in normal direction of rolling is equal to the strain in the rolling direction, i.e., $\dot{\varepsilon}_{33}=-\dot{\varepsilon}_{11}$. Accordingly, two dimensional strain states can be represented by $\dot{\varepsilon}_{11}$ and $\dot{\varepsilon}_{13}$. Since rolling direction strains in the sample A and sample B are consistent with experimentally measured normal direction strains, the characteristics of the strain states in aluminum sheets can be best represented by shear strain rate $\dot{\varepsilon}_{13}$. Variations of shear strain gradients of the mid sheet and the center sheet of sample A and sample B during roll cladding are plotted as a function of the FEM time. During roll cladding the shear strain rate, $\dot{\varepsilon}_{13}$, of the mid AA3003 sheet in the sample A increases positively upon roll entry and decreases to negative value after the neutral point of the roll, finally reaching zero at the roll exit. It can be noticed that non homogeneous strain states were evolved along the through thickness of the mid sheet in the sample A. The shear strain rate at the surface layer (s=1) deviated far from the plain strain condition and that at center layer (s=0) deviated less from the plain strain condition. The shear strain rate of the center AA3003 sheet of sample A is different from that of the mid AA3003 sheet. The shear strain rate of the surface layer (s=1) deviated less from the plain strain condition and that of the center layer (s=0) approximated the ideal plain strain condition. The shear strain rate at the surface layers (s=1 and s=-1) of the mid AA3003 sheet of sample B deviated much far from the ideal plain strain condition and even the shear strain rate of the center layer (s=0) deviated far from the plain strain condition .

4.3. Texture simulation

The strain history derived by the FEM simulations can be used to model the resulting deformation texture. In order to simulate the texture evolution accompanying roll cladding, initial textures of AA3003 sheet were discretized into sets of about 3,500 to 4,500 individual orientations with equal weights. The strain gradients $\dot{\varepsilon}_{ij}$ given by the FEM calculations were fed into Taylor full constraint model.

The simulated textures depicted the deformation textures obtained experimentally. The textures of the upper surface layer (s=1) and center layer (s=0) of the mid AA3003 sheet of sample A displayed mixtures of {001}<110> orientation and {111}//ND orientations, while the textures of the lower surface layer (s=-1) displayed {001}<100> cube orientation and a weak β-fiber with a weak P orientation. The textures of the surface layer (s=1) of the center AA3003 sheet of sample A displayed cube texture and a more intensified β-fiber, while the textures of the center layer (s=0) of the center AA3003 sheet displayed only a typical β-fiber. Here, it should be noticed that even though the intensity of {011}<122> P orientation decreased after deformation, P orientation retained appreciable intensity. The simulated textures of the mid AA3003 sheet of sample B revealed a strong intensity of {001}<110> orientation and a medium intensity of {111}<uvw> orientations through the entire thickness layers. Since the strain states fed into Taylor full constraint model reproduced experimentally obtained textures, it is concluded that the strain states presented in this study were verified by the texture simulations.

As described else where , the evolution of textures during roll cladding strongly depends on the ratio of $|\varepsilon_{13}|/|\varepsilon_{11}|$, where $|\varepsilon_{ij}|$denotes the integration of $|\dot{\varepsilon}_{ij}|$ over deformation time. The results of the FEM simulations and the texture experiments are graphically represented. Evidently, shear textures developed for strain states characterized by $|\varepsilon_{13}|/|\varepsilon_{11}|>0.7$, while strain states with $|\varepsilon_{13}|/|\varepsilon_{11}|<0.5$ led to the formation of a plane strain rolling texture.

5. Conclusions

Two kinds of five ply clad composites were produced by roll cladding. The deformation behavior, the evolution of strain states and textures of individual sheet were discussed and concluded as follows.

A. When layer sheets were of the same kind, the sheet located in the center layer had more thickness reduction than that in the mid layer or in the outer layer.

B. The significant deformation of STS430 sheet sandwiched by AA3003 sheets can be explained by the deformation compatibility between STS430 sheet and AA3003 sheets.

C. The strain states of each layer sheet affected the evolution of textures and microstructures, i.e., a larger shear strain induced the formation of shear texture and fine grains in AA3003 sheets.

D. Based on FEM results and experimental/simulated textures it can be concluded like this: Shear textures developed for strain states characterized by $|\varepsilon_{13}|/|\varepsilon_{11}|>0.7$, while strain states with $|\varepsilon_{13}|/|\varepsilon_{11}|<0.5$ led to the formation of a plane strain rolling texture.