Comparison between ARB and CARB processes on an AA5754/AA6061 composite

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Abstract. The present work aims to compare two processes: Accumulative Roll Bonding and Cross Accumulative Roll Bonding (CARB). Both processes consist in the repetition of rolling but the second technique adds a 90° rotation of the sheet around its normal direction between each rolling. Microstructure, mechanical properties and texture were compared for both processes on an AA5754/AA6061 composite. As a result a thinner and less elongated microstructure was obtained in the CARB process leading to an isotropy and an improvement of the mechanical properties. Besides, the texture was characterized by the rotated Cube component for both processes but for CARB it is of less strength.

1. Introduction

Accumulative Roll Bonding (ARB) process [1] is a recent promising Severe Plastic Deformation (SPD) technique [2]. As a SPD technique, it is well suited to produce UltraFine Grains (UFG) which enhance the mechanical properties. In the literature, ARB was applied on two sheets of a single phase material [3], or of different alloys of the same material [4] or of different materials [5]. These last studies evidenced the efficiency of ARB to create metallic composites with tailored properties. More recently another process close to ARB was developed: the Cross Accumulative Roll Bonding (CARB) [6]. It was used to spread B$_4$C particles in the aluminium matrix [7]. The results showed that the CARBed composite had better mechanical properties than the ARBed one. In the present work, both processes are performed to elaborate an aluminium composite. It is composed of aluminium alloy AA6061, widely used in all metallurgical industries (automotive, aerospace, ...) and aluminium alloy AA5754 which is commonly used for welded structures in nuclear, chemical and food industries. The present work aims to investigate the difference between ARB and CARB at 350°C. A comparison will be given of microstructure, texture and mechanical properties.

2. Materials and experiments

Commercial AA5754 and AA6061 were used in H111 (annealed) and O (prehardened) states, respectively. Their composition is given in Table 1.

Table 1: Chemical composition of AA5754 and AA6061 (weight %)

| Alloy  | Element | Si  | Fe  | Cu  | Mn  | Mg   | Cr   | Zn  | Ti  |
|--------|---------|-----|-----|-----|-----|------|------|-----|-----|
| AA5754 | 0.4     | 0.4 | 0.1 | 0.5 | 2.6-3.6 | 0.3  | 0.2 | 0.15 |
| AA6061 | 0.4-0.8 | 0.7 | 0.15-0.4 | 0.15 | 0.8-1.2 | 0.04-0.35 | 0.25 | 0.15 |

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Sheets of both alloys with a length and width of 30mm and a thickness of 1 mm were perforated because wires were used to hold the stacked sheets. Then both sheets were rinsed with acetone and brushed. Finally, wires are introduced in the previous created holes and tied up. The stacked sheets were annealed at 350°C for 10 min and rolled to 50% of thickness reduction at the same temperature in order to favor a good bonding. The sheet obtained was then cut and the protocol restarted. In the case of CARB, the sheet was turned by 90° before each rolling cycle around its normal direction (ND), changing the rolling direction (RD) for the next rolling.

Figure 1: Principle of the ARB and CARB processes

The comparison of both processes was established after 5 cycles. Microstructures were obtained by EBSD with a scanning electron microscope FEG-SEM SUPRA 55 VP operating at 25kV on the cross-section (perpendicular to the rolling direction). The EBSD measurements were performed on an area of 100 x 100 µm² with a step size of 0.1 µm and analyzed with OIM™ software. The texture was also measured in the cross-section using the X-ray radiation Kα of cobalt with an incident angle of 37°. Three pole figures {200}, {220} and {111} were measured with a curve detector, the {220} one being in Bragg conditions. Data were treated by the Arbitrary Defined Cell (ADC) method. Hardness was measured with a Leco M400H on both sides of the samples in order to have informations on both alloys. The load was 50 g and applied during 10 sec. Ten measurements were averaged for both sides. Tensile tests were performed with a Zwick Roell XForce P 10 kN on both transverse and rolling directions at room temperature with a strain rate of 6.7 10⁻³ s⁻¹.

3. Results and discussion

Figure 2 shows the EBSD-reconstructed microstructures after 5 cycles of ARB and CARB processes in the ND-TD (normal direction - transverse direction) - plane. These maps show grain boundaries separated into two groups: High Angle Grain Boundaries (HAGBs) meaning a misorientation θ>15° and Low Angle Grain Boundaries (LAGBs: θ<15°). They were measured in the area around the last created interface in order to have informations on both materials. The interface is composed of black points in the maps corresponding to non-
indexed points meaning that the composite is not perfectly bonded. Electropolishing prior to EBSD analyses also destroyed precipitates resulting in holes.

![Microstructures](image)

**Figure 2**: Microstructures after 5 cycles of a) ARB and b) CARB. The black lines correspond to the HAGBs, the red ones to LAGBs.

These maps permit to distinguish both processes with regard to crystallite size which was measured in transverse and normal directions and averaged. While ARB shows large crystallites (9 µm for AA5754 and 20 µm for AA6061), CARB has quite smaller crystallites (2.5 µm) whatever the alloy. Let us note that the initial grain size was 30 µm and 120 µm for AA5754 and AA6061, respectively. Moreover, the crystallites are more equiaxed for the CARB process (aspect ratio (ratio between the lengths along TD and ND) of 0.3 for ARB and 0.6 for CARB)). The HAGB fraction is slightly higher for CARB (35%) than for ARB (26%). This indicates that the grain refinement process is more advanced for the CARB process but remains low.

Typical nanograins are not observed because of the high temperature used for both processes (T>0.5T_m, T_m = melting temperature) which prevents more refinement. This also explains why the HAGB fraction is quite low in comparison with the literature (so for example, about 90%, in the case of AA5083 after 5 cycles at room temperature [8]).

The ARB and CARB microstructures are dissimilar: CARB presents thinner and more equiaxed crystallites than ARB. Alizadeh [7] explained that the 90° rotation refines the microstructure which is in agreement with the present work. Another work on 90° rotation effect on the grain size evolution but with Equal Channel Angular Extrusion (ECAE) [9] seems to promote this hypothesis. On the contrary, an unidirectional rolling elongates crystallites along RD, while during the CARB process the change of RD at each cycle prevents this phenomenon.
Textures were also measured and \{100\} calculated pole figures are shown in Figure 3. The texture is described in the rolling plane.

Figure 3: \{100\} pole figures after 5 cycles of a) ARB and b) CARB

Whatever forming technique used, only the \{100\}<110> (rotated Cube) component dominates. The presence of this component can be imparted to the redundant shear strain which is imposed at the sheet surface at each rolling cycle and the redistribution of the orientation occurring after each stacking [8]. Yet, it is more intense in ARB than in CARB process. For the last process, the component is hardly detected. The change of rolling direction does not change the rotated Cube component presence but seems to prevent its development.

Hardness measurements were also compared and results are summed-up in Table 2 for both AA5754 and AA6061.

Table 2: Microhardness at 5 cycles of ARB and CARB

| Alloy   | Process | ARB       | CARB      |
|---------|---------|-----------|-----------|
| AA5754  |         | 77 ± 4.5 HV | 77 ± 6 HV |
| AA6061  |         | 68 ± 3 HV  | 87 ± 9 HV |

Results are the same for ARB and CARB for AA5754 but not for AA6061 where a higher value is obtained for CARB. These results are consistent with the grain size results because those are similar in the case of AA5754 but significantly different for ARB and CARB for AA6061. To conclude, for 5 cycles, the CARB process provides a slightly better hardness than the classical ARB.
Tensile tests at room temperature were also performed in the roll (R) and transverse (T) directions for both processes after 5 cycles (Figure 4).

![Figure 4: Tensile curves in roll direction and transverse direction for ARB and CARB processes (5 cycles)](image)

There is a clear distinction between the ARB and the CARB processes. ARB presents a higher yield strength in TD of 217 MPa compared to RD where it reaches 207 MPa. With the CARB process, the yield strength reaches 239 MPa whatever the loading direction and moreover is higher than for ARB. These results are in agreement with the more equiaxed microstructure produced by CARB which leads to an isotropy of the mechanical properties. Besides, it is worth noticing that the ductility is increased. Thus, an isotropy and an improvement of the mechanical properties are obtained after 5 cycles with the CARB process.

4. Conclusion

The CARB process has two major effects on the microstructure: it leads to a grain size refinement and an equiaxed grain shape that induce an isotropy and an improvement of the mechanical behavior. Moreover, the 90° rotation randomizes the texture. Thus, CARB could be suited to elaborate composites with isotropic and enhanced mechanical properties. However, it may be interesting to decrease the rolling temperature to minimize dynamic recovery and recrystallization effects and by this decrease the grain size and increase the HAGB fraction.

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