JP&M Engineering
Journal of Petroleum and Mining Engineering

Studying the Effects of Accumulative Roll Bonding Cycles on the Mechanical Properties of AA1050 Aluminum Alloy

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Article Info

Received 6 May 2021
Revised 24 May 2021
Accepted 30 Nov. 2021

Keywords

Pure Aluminum; Preheated; Accumulative Roll bonding; Ultimate Tensile Strength (UTS); Strain-Hardening Coefficient.

Abstract

Accumulative Roll Bonding (ARB) is a prospective severe plastic deformation (SPD) process that can continuously produce bulk material and has good commercialization potential. This paper aims to study the effect of different ARB cycles in details on tensile strength, elongation, and strain-hardening coefficient. Aluminum sheets AA1050 were heated at 300ºC, then rolled for a single pass with 67% reduction in thickness and air cooled. The produced sheet was cut and accumulative roll bonded (50% reduction) after reheating at 280ºC with different ARB cycle regimes. The tensile testing was carried out at room temperature after different cycles of ARB. Ultimate tensile strength, elongation, and strain-hardening coefficient were determined. The results indicated that UTS after ARB is significantly improved by accumulative roll bonding achieving 121% of AA1050. This improvement is attributed to the reduction of grain size and increasing the grain boundaries. However, the total elongation percentage were reduced, at which the elongation reduced by a factor 95% of AA1050."

Introduction

AA1050 unalloyed (pure) composition, used to manufacture some structural parts with specific properties, such as gaskets and capacitors made of aluminium foil, shell of electronic products, isolation network of electronic tubes, protective sheaths of wires and cables, nets, wiring cores and parts and decorations of airplane ventilation system [1]. However, the poor mechanical properties of aluminum—low hardness and strength—narrow the range of its possible applications.

Bay [2] found that the bonding strength of a cold-welded Al/Al combination approaches the strength of the parent metals at high levels of surface expansion. Saito et al. [3] found that severe plastic deformation (SPD) is one of the most effective technology to produce ultra-fine grained (UFG) materials, with a mean grain size smaller than 1µm, in bulk materials. The UFG Al/Al are promising materials having prominent mechanical properties.

Different SPD methods create ultra-fine-grained structures of high-angle grain boundaries, which means many obstacles against dislocation motions [2-6]. Furthermore, SPD produces uniform nanostructures having stable properties of the processed materials and not suffering from any defects or mechanical damage [7-11]. ARB consists of multiple cycles of rolling, cutting, stacking, and solid-state deformation bonding so that a significant strain can be accumulated in the metallic sheet without free spread. Particularly, ARB is a prospective SPD process that can produce bulk material continuously and has a good potential for commercialization [12-13]. This paper aims to study the effect of different ARB cycles in details on tensile strength, elongation, and strain hardening coefficient.

Experimental Work

The materials used in this study are fully annealed strips of commercial purity aluminum alloy AA1050 (specifications are shown in Table 1). The aluminum sheet's dimensions are length, width, and thickness 330mm×150mm×1.5mm strips. Preparation of sheets was carried out by cleaning and degreasing the aluminum surface using acetone solution.

The sheet samples of aluminum were wire brushed (scratching) and then two layers assembled. Assembled aluminum sheets were heated at 300ºC for 5minutes and then rolled for a single pass with 67% reduction in thickness and cooled in the air (0 Cycle).

The produced thickness was 1 mm. Table 2 demonstrates the technique used in the accumulative roll bonding process and determines the specific condition and terms for each stage at different cycles.

Table 1 Chemical composition and mechanical properties of Al 1050

Material	Chemical composition (Elements wt.%)							Hardness	Elongation	Yield strength	UTS
Al1050	Al	Fe	Si	Cu	Mg	Mn	Ti	(HV)	(%)	(MPa)	(MPa)
annealed	99.55	0.3	0.09	0.002	0.003	0.005	0.05	24	38	39	48

Table 2 Regime of the ARB process for the production of AA1050

No. of cycles Rolling	Preheated Temperature(^{o}C)	No. of Al-layers	Reduction in each cycle (%)	Total reduction (%)
0	300 for 5min.	2	67	67
Annealing at 400°C for 60min. and then furnace cooled				
1	280 for 7min.	4	50	50
2	280 for 7min.	8	50	75
3	280 for 7min.	16	50	87.5
4	280 for 7min.	32	50	93.75
5	280 for 7min.	64	50	96.87
6	280 for 7min.	128	50	98.43
7	280 for 7min.	256	50	99.21
8	280 for 7min.	512	50	99.6

The rule for choosing different annealing and heating temperatures is the combination of previous studies [7-8], and the initial attempts of the alloy under investigation and taking into considerations the potentials available in the CMRDI. Fig. 1 illustrates the process schematically.

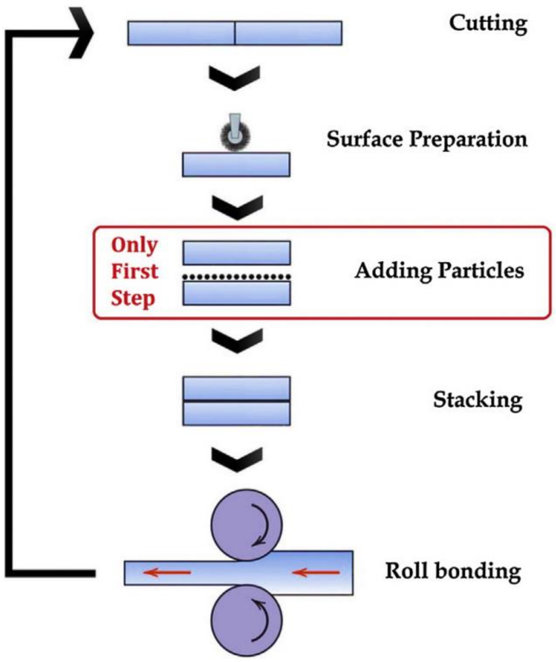

Figure 2 Schematic illustration of (ARB).

After the zero cycle, the sample is annealed at 400^{o}C for one h to remove the strain exerted in the zero cycle. Tension samples were prepared according to ASTM E8M. The tension test was carried out according to the ASTM standard E8M at room temperature on a universal testing machine (1000kN) with a constant crosshead speed of 0.5 mm/min. The dimension of the tension sample is demonstrated in Fig. 2.

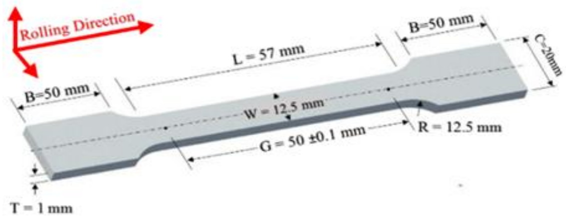

Figure 2 Dimensions of ARB tensile specimen (ASTM E8M).

Results and Discussions

Figure 3 demonstrates the engineering stress-strain diagram of AA1050. It is apparent that the proof strength is 40MPa, ultimate tensile strength UTS is 68.5MPa, and the total elongation is 31.7%. The initial strain hardening coefficient of AA1050 is 0.117, as shown in Figure 4. However, during tensile testing, the strain hardening coefficient changes to reach 0.216 due to strain accumulation at an engineering strain of 1.9%.

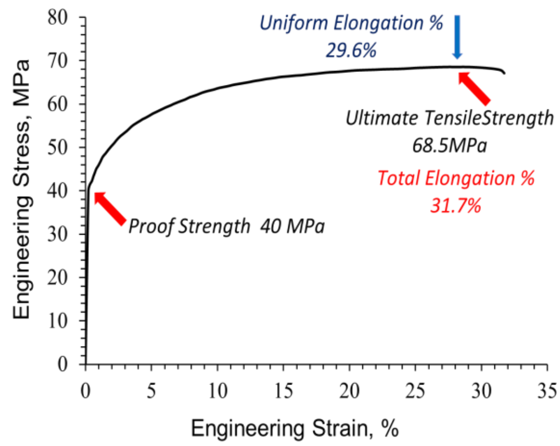

Figure 3 The engineering stress-strain diagram of AA1050.

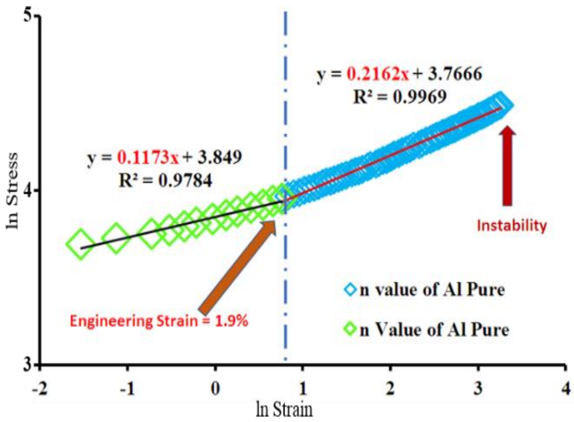

Figure 4 Strain-hardening Coefficient of AA1050.

Figure 5 represents the stress-strain behavior of AA1050 after different cycles of accumulative roll bonding. It is clear that total elongation percentage (pct.) decreased from the initial value of AA1050 due to accumulative roll bonding, as seen in Figure 6. The elongation pct. of ARB decreased due to severe plastic deformation.

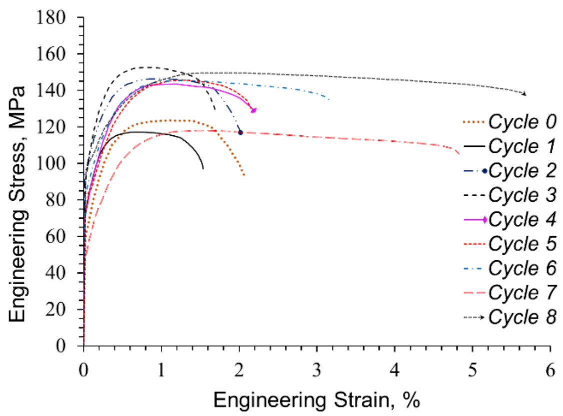

Figure 5 Engineering Stress-Strain Curves of AA1050 after 8 Cycles Accumulative Roll Bonding.

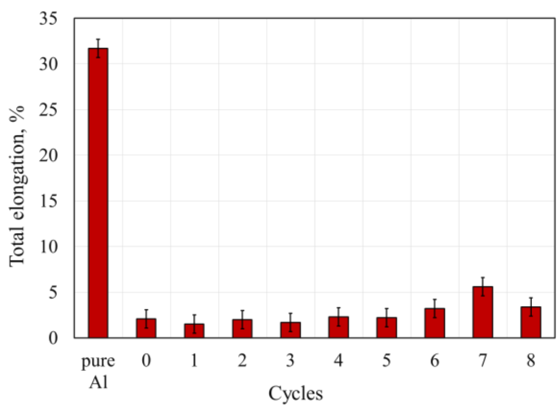

Figure 6 Effect of no of Cycles on Total Elongation pct. of AA1050.

On the other hand, the UTS increased to 117-151MPa, an increasing 90-121% ratio. Furthermore, after accumulative roll bonding, the total elongation percentage is a decreasing ratio of 82-95%, as seen in Figure 7. It is clear the UTS increases after cycle 1 (67%ARB+annealing +50%ARB) with a ratio of 19%. After Cycle 2 to cycle 6, the material shows constant UTS due to dynamic recovery [13].

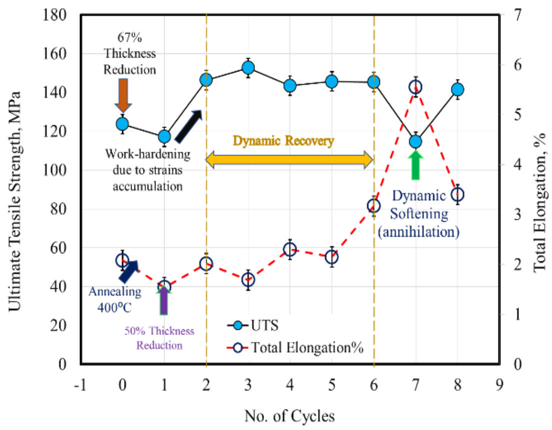

Figure 7 Relationship between no. of cycles and Tensile properties (UTS and Total elongation pct.) for AA1050.

After cycle 6, the material shows sudden softening, i.e. (decrease of UTS and increase of Elongation pct) due to dynamic recrystallization. After cycle 7, the material exhibits work-hardening. The stress-strain behavior can be judged using the strain-hardening coefficient tool. It is clear that the strain-hardening coefficient of cycle 0 is 0.28 (relatively high) due to applying a 67% reduction in thickness, while for cycle one, the strain-hardening coefficient decreased because the material was annealed at 400°C for 60 minutes after cycle 0. At cycles 2 and 3, the material shows approximately constant strain hardening coefficient (0.16-0.18) due to the preheating (280°C for 7 minutes) before the ARB process. After cycles 4 and 5, the strain hardening coefficient increases due to strain accumulation (more dislocation). After cycle 6 the material exhibits slight decrease of strain hardening coefficient due to dynamic recovery.

Figure 8 demonstrates the strain-hardening behavior during tensile testing after different cycles of treatment (0-8Cycles). It seems clear that all tensile samples undergo three zones of strain-hardening. The first zone is the strain-hardening accumulation for all samples and finishes at around 0.07% of total elongation. The first zone shows a low strain-hardening coefficient of ARB samples (n=0.05-0.1). On the other hand, the second zone starts directly after the first one. The second zone exhibits a high strain-hardening coefficient (n=0.16-0.29).

The strain-hardening coefficient depends on the previous state of the materials (i.e., previously softened or hardened or dynamically recovered), such as cycle1, 2, and 3, where the strain-hardening coefficient decreases due to dynamic recovery. For Cycles 4, 5, 6, and 7, it is apparent that the ARB materials repeat the strain-hardening increasing and decreasing due to strain accumulation, dynamic strain softening, and reheating between cycles. Figure 9 describes the strain-hardening behavior after ARB cycles.

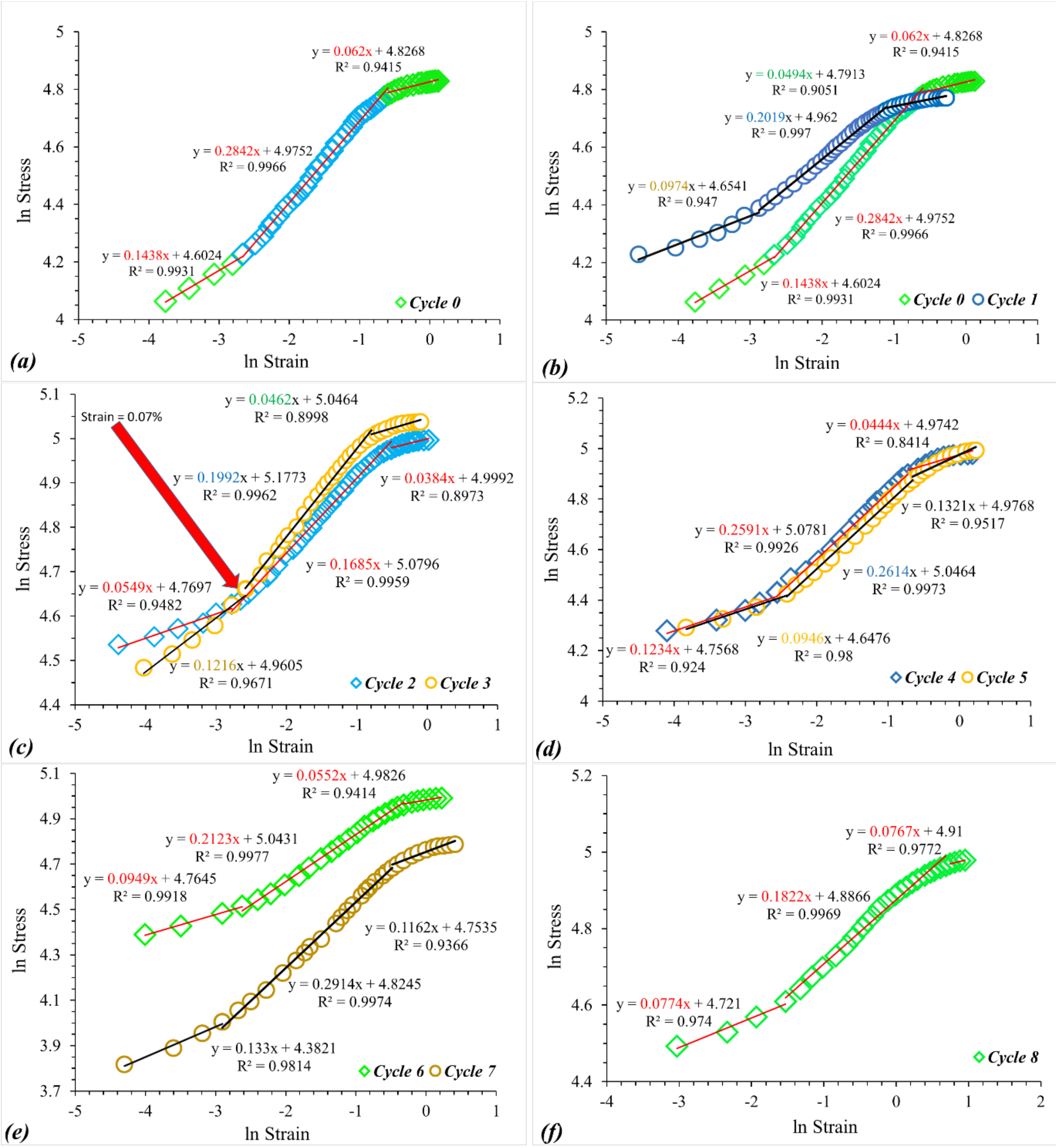

Figure 8 Effect of ARB cycles on the strain-hardening coefficient for AA1050.

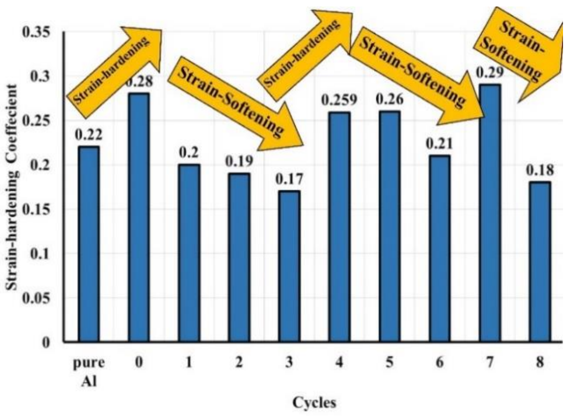

Figure 9 Summary of Maximum Strain-hardening Coefficient of ARB Aluminum.

Conclusions

The manufacturing of AA1050 were successfully produced through accumulative roll bonding technique.

- The result indicated that the total elongation percentage has decreased than the initial value of AA1050 due to accumulative roll bonding.
- The UTS after ARB increased to reach 151MPa with a ratio 121% of AA1050, the used accomulative roll bounding led to producing improved mechanical performance, therfore the accumulative roll bonding lead to dislocation strengthening, and grain size strengthening.
- Furthermore, after accumulative roll bonding, the total elongation percentage decreased with a ratio 82-95% of AA1050. Strain-hardening coefficient increases and decreases according to the previous

Al sheet state (i.e., prior work-hardening of softening conditions)

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