

# Effect of processing cycles on aluminum/tungsten carbide composites prepared by continual annealing and press bonding process

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**Abstract.** In the present work, a novel technique is introduced called CAPB (continual annealing and press bonding) for the manufacturing of a bulk aluminum matrix composite dispersed with 10 vol.% WC particles (Al/WC<sub>p</sub>). The microstructure of the fabricated composite after fourteen cycles of CAPB showed an excellent and homogenous distribution of the WC particles in the aluminum matrix and strong bonding between the various layers. The results indicated that the tensile strength of the composites increased with the number of CAPB cycles, and reached a maximum value of 140 MPa at the end of fourteenth cycle, which was 1.6 time higher than the obtained value for annealed aluminum (raw material, 88 MPa). Even though the elongation of the Al/WC<sub>p</sub> composite was reduced during the initial cycles of CAPB-ing, it increased significantly during the final cycles.

**Keywords.** Metallic composites; Metal forming and shaping; Mechanical properties; Laminates; CAPB process

## 1. Introduction

Conventional manufacturing processes for composites (e.g., casting, powder metallurgy, etc.) are not suitable for producing bulk Al/WC<sub>p</sub> composites, because of the significantly higher density and melting point of WC<sub>p</sub> (15.63 gr/cm<sup>3</sup>, 3143 K) compared with aluminum (2.70 gr/cm<sup>3</sup>, 930 K) [1, 2]. Recently, we developed an improved process named accumulative press bonding (APB) for manufacturing aluminum matrix composites (AMCs) [3]. In the present investigation, we now introduce an alternative solid state process for the production of AMCs, namely continual annealing and press bonding (CAPB). A major disadvantage of press-bonding methods is the fact that strain accumulation occurs as the number of cycles increase. CAPB aims to overcome this short-coming by using annealing strips after each cycle of press-bonding to exactly prevent such strain accumulation. Therefore, the objective of the present investigation was to determine if production of Al/WC<sub>p</sub> composites by this novel process was feasible and to study the effect of the number of CAPB cycles on the microstructure and mechanical properties of the as-produced Al/WC<sub>p</sub> composite.

## 2. Experimental procedure

As-received commercial AA1050 aluminum strips with the dimensions of 100 mm × 50 mm × 1.5 mm were annealed at 623 K in ambient atmosphere for 1 h, and WC powder with an average particle size of about 10 μm were used as raw materials. The CAPB process for manufacturing of the Al/10 vol.% WC<sub>p</sub> composite is schematically depicted in Fig. 1.



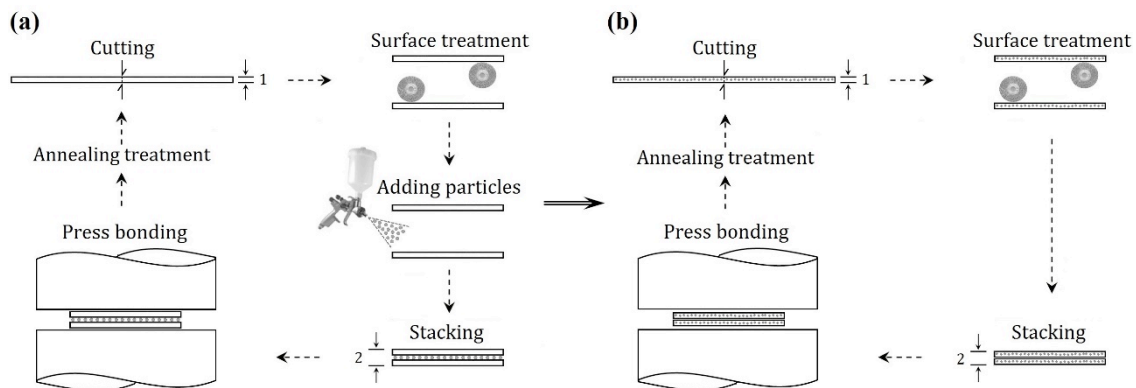


Fig. 1. Schematic overview of the production stages involved in the fabrication of the Al/WC<sub>p</sub> composite strip via the CAPB process. (a) First stage: addition of WC particles between the strips, (b) Second stage: removal of discontinuities between the layers and dispersion of the WC particles in all parts of the aluminum matrix.

After surface preparation (degreasing and wire brushing), the ultrasonicated WC powder in acetone was sprayed between the two aluminum strips with an atomizer. Upon WC particle deposition and air evaporation of the acetone, the brushed surface of one strip was uniformly covered with WC particles. Subsequently, the two strips were placed on each other and stacked, and were carefully handled to avoid contamination. Cold press bonding was performed on the stacked strips with no lubrication, employing a laboratory hydraulic press machine (Toni Technik Baustoffprüffsysteme GmbH, Berlin, Germany), with a loading capacity of 200 tons. The press bonding process was carried out with a specific amount of reduction equal to 50%. Then, the press bonded strips were cut in half and annealed again. The same procedure was repeated up to five cycles in the first stage (Fig. 1a). In the second stage (Fig. 1b), the aforementioned procedure was repeated up to fourteen cycles without adding WC<sub>p</sub> powder. To characterize the microstructure of the specimens throughout the different number of CAPB cycles, scanning electron microscopy (SEM) was carried out on a Philips XL30 scanning electron microscope (Philips Electron Optics B.V./FEI, Eindhoven, the Netherlands). For tensile strength testing, test specimens were machined from the CAPBed strips according to the ASTM E8M standard. The tensile test was carried out at a nominal strain rate of  $1.6 \times 10^{-1} \text{ s}^{-1}$  with a Hounsfield H50KS TM tensometer (Tinius Olsen Ltd, Redhill, UK).

### 3. Results and discussion

The microstructure of the Al/WC<sub>p</sub> composite in the plane perpendicular to the press direction during the CARB process is depicted in Fig. 2. After seven cycles (Fig. 2a), large particle free zones were observed, alternated by large clustered concentrations of particles. In the first stage of CAPB process where particles were added between the aluminum strips, the WC reinforcement particles easily formed large clusters because of their large surface to volume ratio and attractive van der Waals interactions. Fig. 2a shows that these clusters existed even after two cycles of second stage (seventh cycle of the CAPB process). After the fourteenth cycle (Fig. 2d), both clusters and particle free zones were no longer apparent and a uniform Al/WC composite was formed. Therefore, with increasing number of CAPB cycles, an increased uniformity of WC particles and distribution within the aluminum matrix was achieved. These phenomena may be attributed to the high deformability of the matrix after annealing treatment. Plastic flow of the aluminum matrix causes fragmentation of the WC particle clusters and separation of the individual WC particles, and, consequently, a more uniform distribution throughout all parts of the matrix is accomplished.

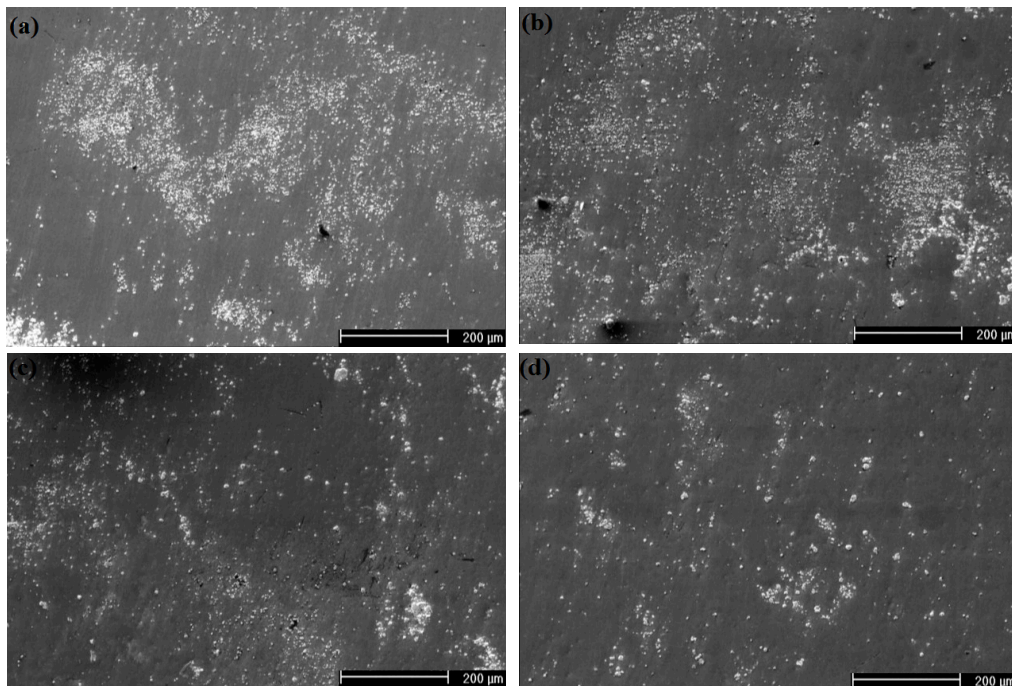


Fig. 2. Representative SEM micrographs of the Al/WC<sub>p</sub> composite microstructures at planes perpendicular to the press direction after: (a) seven, (b) nine, (c) eleven, and (d) fourteen CAPB cycles.

Evaluation of the tensile strength of the Al/WC<sub>p</sub> composite relative to the number of CAPB cycles is shown in Fig. 3. Due to the annealing process at the end of each CAPB cycle, a sequence of recovery, recrystallization, and grain growth occurs and the work hardening effect is almost eliminated.

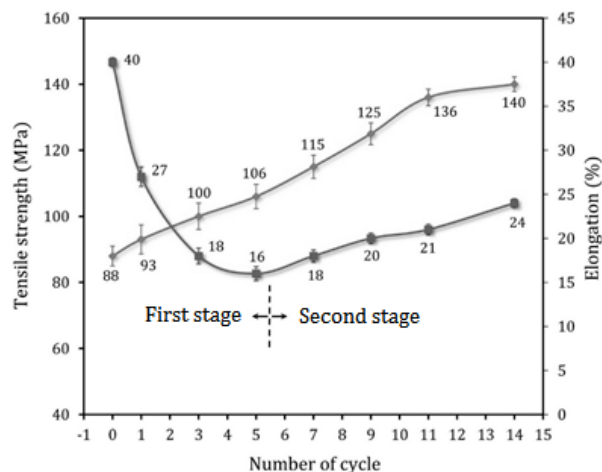


Fig. 3. Variations of the tensile strength and the elongation of Al/WC<sub>p</sub> composite versus the number of CAPB cycles.

In the first stage of the CAPB process, WC particles were added to the aluminum matrix, and, therefore, the particle volume fraction in the aluminum matrix was increased. It has been widely reported that increasing the amount of reinforcement in the aluminum matrix significantly increases the tensile strength [4, 5]. On the other hand, as mentioned before, in the second stage, CAPB was performed without adding WC particles. In this stage, when the number of CAPB cycles increased, the uniformity of the particles in the matrix improved and

better bonding was also achieved between the particles and matrix, which resulted in higher strength. The tensile elongation of the Al/WC<sub>p</sub> composite versus the number of CAPB cycles is also shown in Fig. 3. The results show that the tensile elongation decreased dramatically from 40% (for the annealed raw material) to 16% in the first stage. This significant decrease may be attributed to the presence of the added WC particles in the aluminum matrix in the first stage, which hinder the dislocation movement. In the second stage, it is obvious that the elongation increased with increasing number of CAPB cycles from 16% to 24%, which represent a 50% improvement. It should be noted that the second stage greatly increased both the tensile strength and the elongation of the composite due to a higher degree of homogeneity in the WC particle distribution in the matrix. Reducing the agglomeration and clustering of particles retard the link-up of cracks between particles at the clusters, increasing ductility. At the same time, reducing the particle free zones and decreasing the average distance between individual particles enhance the tensile strength.

#### 4. Conclusions

The conclusions drawn from the results can be summarized as follows:

1. By combining WC<sub>p</sub> powder and AA1050 strips, a bulk Al/WC<sub>p</sub> composite was successfully produced up to fourteen cycles of the CAPB process.
2. With increasing number of CAPB cycles increased, the uniformity of the WC particles in the aluminum matrix and the bonding quality between layers and between particles and matrix improved significantly. The final composite product after the fourteenth cycle showed a high degree of homogeneity of particle distribution and particle size.
3. The tensile strength of the composites increased with increasing number of CAPB cycles, and reached a maximum value of 140 MPa at the end of the fourteenth cycle, which was 1.6 times higher than the value obtained for the initial material (88 MPa).
4. The elongation of the Al/WC<sub>p</sub> composite decreased in the first stage of the CAPB process, only to increase significantly during the second stage, as a result of the improved homogeneity of particle distribution and the bonding quality.

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