doi:10.1017/S1431927619004653
Microsc. Microanal. 25 (Suppl 2), 2019

# Interfacial Phases in a Graphene-Doped Aluminum/$B_4C$ MMC

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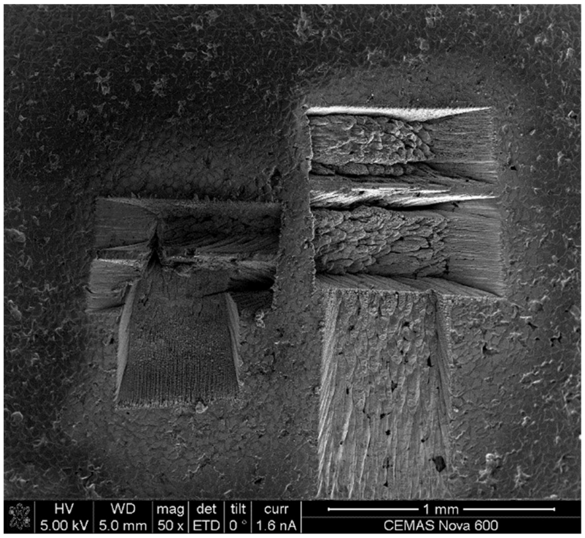
Al-Si alloys are light, corrosion resistant, easily processed, and are widely used in the automotive industry [1]. However, due to their low wear resistance they are often reinforced with hard ceramic particles such as boron carbide ($B_4C$) [2]. Since the ceramic particles can damage the counter material [3], graphene nanoparticles were added to the surface of the $B_4C$ to improve the wear resistance and lubricity. In $B_4C$ reinforced aluminum alloys, silicon and other alloying elements are used to minimize the reaction between the aluminum and $B_4C$ [4]. This $B_4C$-reinforced aluminum alloy (12 w% Si, 0.6% Ni, 0.5% Mn, 0.1% Fe, 0,15% Ti, 0.1% Mg, 0.1% Zn, 0.1% Pb, 0.05% Sn) was further modified with 1% graphene added to the $B_4C$ to improve the wear resistance, corrosion properties, and lubricity.

The goal was to determine the phases that are at the $B_4C$-aluminum interface and to see if the graphene doping was still visible at the surface of the $B_4C$. In order to see the original distribution of the graphene and interface phases it is necessary to look at the buried interfaces that have not been exposed to any sort of abrasion. However, the extremely slow sputtering rate of the $B_4C$ makes getting good cross-sections difficult. To mitigate this, a Thermo Scientific PFIB with femtosecond laser system was used to create trenches from which a conventional $Ga^+$ FIB could prepare samples in a reasonable time. The laser was able to effectively remove both the $B_4C$ and the aluminum phases (Fig. 1). The exposed interfaces were checked during the FIB process (Fig. 2) and promising interfaces were then later examined in the TEM.

The FIB lift-out membranes were examined in an FEI Tecnai F20 and a Tecnai 30 S/TEM at 200 and 300kV respectively. Figure 3 is a HAADF STEM image illustrating one portion of the interface shown in figure 2. Note that the orientation is flipped from the SEM image. The area to the right contains redeposited material from the laser ablation. The alloying elements in the aluminum were preferentially found at the $B_4C$ interface. Nickel formed an $Al_3Ni$ and an AlCuNi phase at the interface. On the interfaces examined, there was no visible reaction product between the Si and the $B_4C$ or the graphene. The EDX map in Figure 4 shows what appears to be an intact graphene particle on the $B_4C$ surface indicating that it was not dissolved by the Aluminum or Silicon. The other alloying elements such as Chrome, Titanium, Vanadium, and Iron were also found at the interface though they generally formed smaller intermetallic particles as illustrated in figure 4 [5].

## References:

[1] H Ye, Journal of Materials Engineering and Performance **12** (2003), p. 288.
[2] J Ejiofor and R Reddy, Journal of The Minerals, Metals & Materials Society **49(11)** (1997), p. 31.
[3] F Aydın et al., Transactions of the Indian Institute of Metals **71(4)** (2018), p. 873.
[4] AR Kennedy, Journal of Materials Science **37** (2002), p. 317.
[5] The authors gratefully acknowledge support from The Ohio State University, the OSU Institute for Materials Research and the Ohio Third Frontier Research Scholar program.



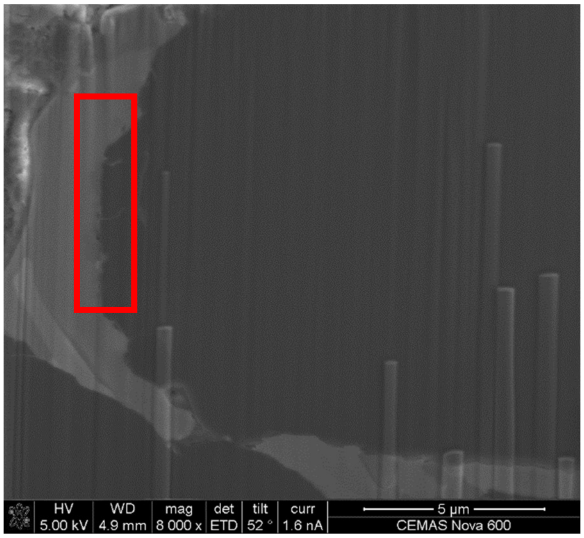
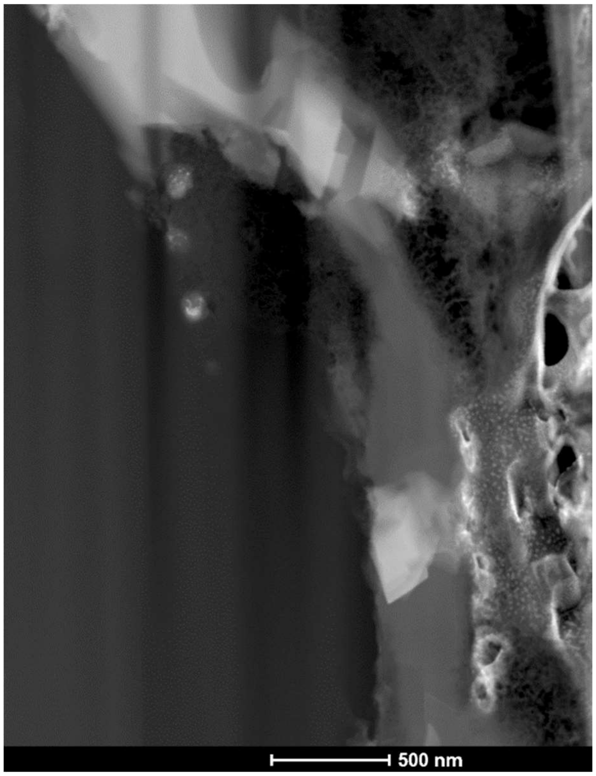


**Figure 1.** Trenches cut by femtosecond laser system in surface of sample.
**Figure 2.** FIB SEM image of buried surface of $B_4C$ particle (dark). Box indicates area used for further analyses. Darker phase next to $B_4C$ particle is Si, lighter phase is Al



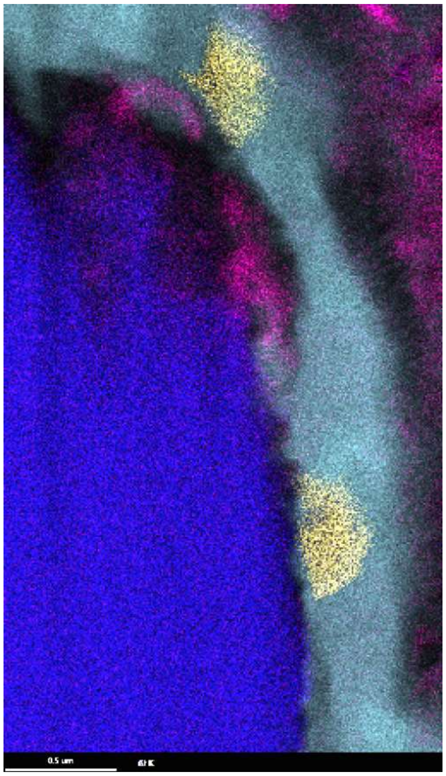


**Figure 3.** HAADF STEM image of an aluminum $B_4C$ (dark) interface
**Figure 4.** STEM EDX map of area from Fig. 3. Blue-Boron, Cyan-Aluminum, Red-Carbon, Yellow-Chrome (also Cu, Ti, V, Fe).