A Failure Analysis of an Experimental $AlMgB_{14}$ Cutting Tool

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A recently developed ultra-hard boride-based material, $AlMgB_{14}$, has been fabricated into a standard cutting tool geometry (TPG-222) and tested using single-point turning of Ti-6Al-4V. The initial testing was conducted to compare this new cutting tool's performance relative to a WC-Co cutting tool. During the tests the boride-based inserts suffered catastrophic failure for a wide range of cutting conditions, and so a failure analysis was conducted on these inserts.

Ti-6Al-4V is a particularly difficult material to machine due to its mechanical properties but also to its low thermal conductivity and high chemical reactivity. Significant improvements in cutting tool materials must be made for real advancements to occur in machining this alloy [1]. An ultra-hard material based on $AlMgB_{14}$ is a promising candidate for use in this application [2]. Borides have very low solubility and limited diffusion in titanium, and $AlMgB_{14}$ material has a hardness that is second only to diamond [3]. Therefore, it is expected that this material will not degrade as quickly as other commonly used cutting tools, such as WC-Co, and is expected to be more economical than cubic Boron Nitride (cBN) materials. The process for fabricating this material was developed at Ames Laboratory, Ames, IA. The process, still in development stages, involves mechanical alloying of elemental powders in a high-energy ball mill and hot pressing the alloyed powders in an inert atmosphere.

Figure 1 shows scanning electron microscope images for two inserts that failed during single-point turning of Ti-6Al-4V using a cutting speed of 30 m/min, a feed rate of 0.25 mm/rev, and a depth of cut of 0.25 mm. The tool inserts have a triangular geometry and the primary mode of failure was nose fracture (see Figure 2). The SEM images in figure 1 reveal excessive porosity on the fracture surface of one of the inserts, suggesting the hot-pressing did not provide full densification. Image B in Figure 1 also shows blocky acicular second-phase particles in the cutting tool material. A crack running through this region shows that the matrix material has pulled away from the second-phase particle. The matrix/particle interface may also lack sufficient strength to provide the tool with adequate mechanical integrity.

Vickers microhardness measurements of this experimental cutting tool material were made using a 1000 gram load and compared with WC-Co inserts. As expected the hardness was higher in the $AlMgB_{14}$ material as is indicated by a smaller Vickers indentation (see Figure 3). The measured hardness for the $AlMgB_{14}$ shown in Figure 2 was HV1000 = 2290 $\pm$ 198 (95% C.I.) and the WC-Co hardness was HV1000 = 1812 $\pm$ 55 (95% C.I.). But it is observed that the cracks emanating from each corner of the Vickers indent were much longer on the $AlMgB_{14}$ material than on the WC-Co material. Crack lengths measurement is a qualitative method of evaluating fracture toughness, such as shown in [5]. This test implies that the fracture toughness of the $AlMgB_{14}$ tool material is

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[1] Commercial equipment and materials are identified in order to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

significantly less than that of the WC-Co material. These tests indicate that the toughness of this material needs to be improved.

In conclusion, the processing of this experimental material is still being optimized at the DoE Ames Laboratory. Achieving full density and implementing a new binder phase will substantially increase the fracture toughness; thereby, making this a potentially viable tool material for improved machining of Ti-6Al-4V [4, 6].

References

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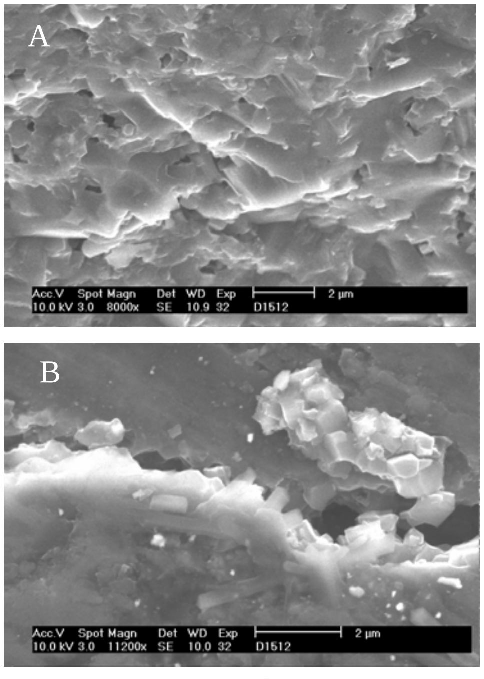

Fig. 1. Scanning electron microscopy images of two fracture surfaces of $AlMgB_{14}$ cutting tools. A. Microporosity is present on the fracture surface. B. The crack interface between the second-phase particle and the matrix material is seen.

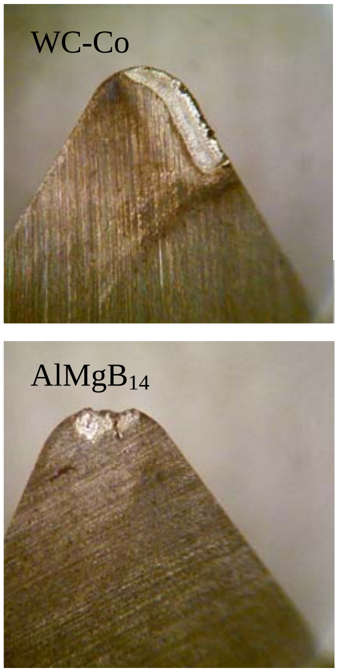

Fig. 2. Optical microscopy images of wear patterns on $AlMgB_{14}$ and WC-Co cutting tools. The $AlMgB_{14}$ presents catastrophic wear (fracture) while WC-Co presents crater wear. Crater wear is an indication of good wear.

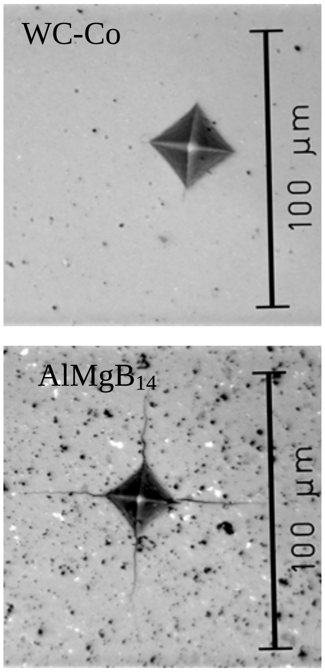

Fig. 3. Optical microscopy images of Vickers microhardness indents on an $AlMgB_{14}$ cutting tool and on a WC-Co cutting tool. The $AlMgB_{14}$ has a higher hardness (smaller indentation), and lower fracture toughness, as indicated by the longer cracks emanating from the corners of the Vickers indents.