Grade Development of Polycrystalline Cubic Boron Nitride for Friction Stir Processing of Ferrous Alloys

Matt Collier[1], Russell Steel[1], Tracy Nelson[2], Carl Sorensen[2], Scott Packer[3]
[1] Sii Megadiamond, Inc., 275 West 2230 North, Provo, UT. 84604, USA
mcollier@smith.com & rsteel@smith.com

[2]Brigham Young University, College of Eng. Technology, 265 CTB, Provo, UT. 84602, USA
tracy_nelson@byu.edu & c_sorensen@byu.edu

[3]Advanced Metal Products, Inc, 2320 North 640 West, West Bountiful, UT. 84087, USA
scott@advmp.com

Keywords: Friction Stir Processing, Cubic Boron Nitride, Stainless Steel

Abstract. Friction stir processing (FSP) of ferrous alloys is possible using polycrystalline cubic boron nitride (PCBN) as the tool material. FSP tool wear characteristics are dependent on the grade of PCBN and the ferrous alloy being processed. Several grades of PCBN were evaluated in machining wear tests using 304L and AL-6XN stainless steels. Mechanical wear, chemical wear, and diffusion wear were the failure modes identified by these tests. These results were correlated with failure modes identified in PCBN tools used to friction stir process 304L and AL-6XN.

Introduction

The microstructure and mechanical properties of ferrous and nonferrous alloys are changed significantly when processed with friction stir processing (FSP) tools (Figure 1) [1-7]. FSP of 304L and AL-6XN requires a tool system to achieve a steady state process at elevated temperatures. The tool system is comprised of a polycrystalline cubic boron nitride (PCBN) tool contained within a metal housing, a liquid cooled tool holder (not shown), and a telemetry system (not shown). The PCBN tool must have the appropriate thermo chemical stability, hot hardness, and abrasion resistance required to process ferrous alloys. The liquid cooled tool holder removes heat from the PCBN tool to achieve steady state operating parameters, and the telemetry system is interfaced with the machine controls to maintain a constant tool temperature.

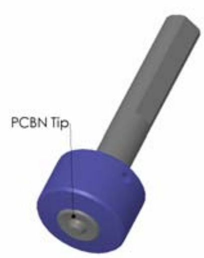

Figure 1 PCBN tool used for FSP

Background

PCBN was developed as a cutting tool material to machine hardened steels, super alloys, and other ferrous materials. PCBN is composed of cubic Boron Nitride (cBN) crystals and a catalytic second phase that forms a solid material. Many cutting tool grades of PCBN are commercially available and are selected according to the requirements of each application. PCBN grade properties can be tailored for specific application requirements. By altering variables such as cBN content, second phase content/type, i.e., metallic and/or ceramic-based systems, and grain size. Generally, abrasion resistance and toughness increase with increased cBN content. Conversely, chemical stability increases with an increased ceramic-type second phase. Furthermore, the coefficient of heat transfer can be changed via the same methods. A database of machining parameters and wear modes for PCBN cutting tools has been established as a basis to develop improved PCBN grades for cutting tool applications.

FSP, on the other hand, is a new technology with several process variables that must be properly controlled. Wear modes as they relate to run parameters have not been established. For this reason, wear modes of PCBN cutting inserts are compared to wear modes of PCBN FSP tools. Figure 2 shows the CBN cutting tool and PCBN FSP tool geometries used to machine or FSP AL-6XN and Figure 3 shows typical wear modes of PCBN observed in conventional lathe turning.

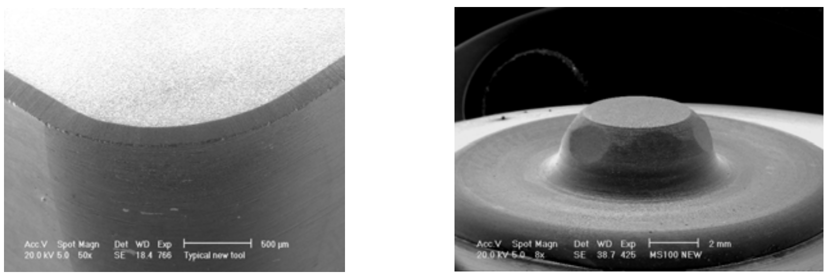

Figure 2 CBN cutting tool (left) and PCBN FSP tool geometry (right).

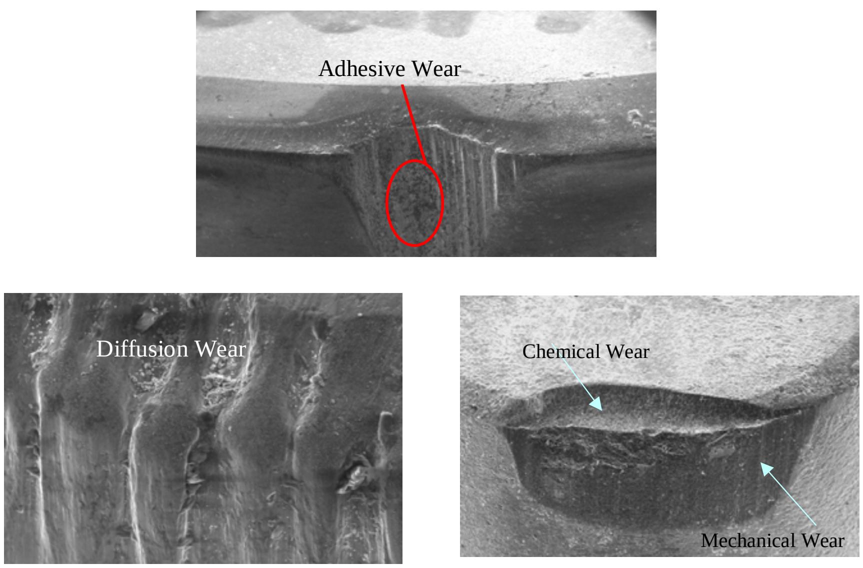

Figure 3 Adhesive wear (top) on the front of the cutting edge, diffusion wear pattern (bottom left), and chemical and mechanical wear (bottom right) at the cutting edge of PCBN observed in standard turning tests.

Experimental Approach

Initial lathe turning tests were performed to select three grades of PCBN that would show different wear characteristics in AL-6XN and 304L stainless steels. The grades selected are shown in Table I.

Table I. PCBN grades selected to evaluate wear modes from machining and FSP.

Grades	Grade Type	Second Phase	CBN Content (vol %)	Vickers Hardness (kg/mm^2)
MN45	Standard grade	Ti	50%	2650-2750
MS100	Standard grade	Al	~93%	2600-2700
801310XP	R&D grade	Ti	80%	2900-3000

A feed rate (f) of 0.13 mm/rev, depth of cut (a_p) of 0.13 mm, and a neutral cutting geometry without coolant provided the most stable and consistent machining parameters to lathe turn AL-6XN with these CBN grades. Surface speeds (V_c) of 76 and 290 m/min were selected as "cooler" and "hotter" machining speeds respectively using the parameters mentioned above. Four inserts of each grade were tested. PCBN FSP tools were also fabricated from the same grades and run in both AL-6XN and 304L stainless steels. FSP parameters included 1000 RPM rotation speed, 25.4mm/min feed, and 8.9 Nm Z axis load. All FSP trails were run in load control for a total time of 49 minutes for each tool. Two PCBN FSP tools of each grade were fabricated for testing.

Results and Discussions

Figure 4 shows a comparison of PCBN machining inserts at the two different surface speeds. In all three grades run at 76 m/min, there was adhesive wear on the top of the insert. Tools fabricated from MS100 showed the most serious adhesive wear while the 801310XP tools showed the least wear. At 290 mm/min, the MN45 showed chipping with slight adhesive wear and the MS100 showed typical mechanical and chemical wear. During the fabrication process of both MN45 machining inserts and FSP tools, slight chipping was visible on most edges. Chipping during fabrication is generally indicative of low PCBN fracture toughness. Machine tools fabricated from 801310XP again performed best and at the higher surface speed 290(m/min) showed less wear than at the lower speed (76 m/min).

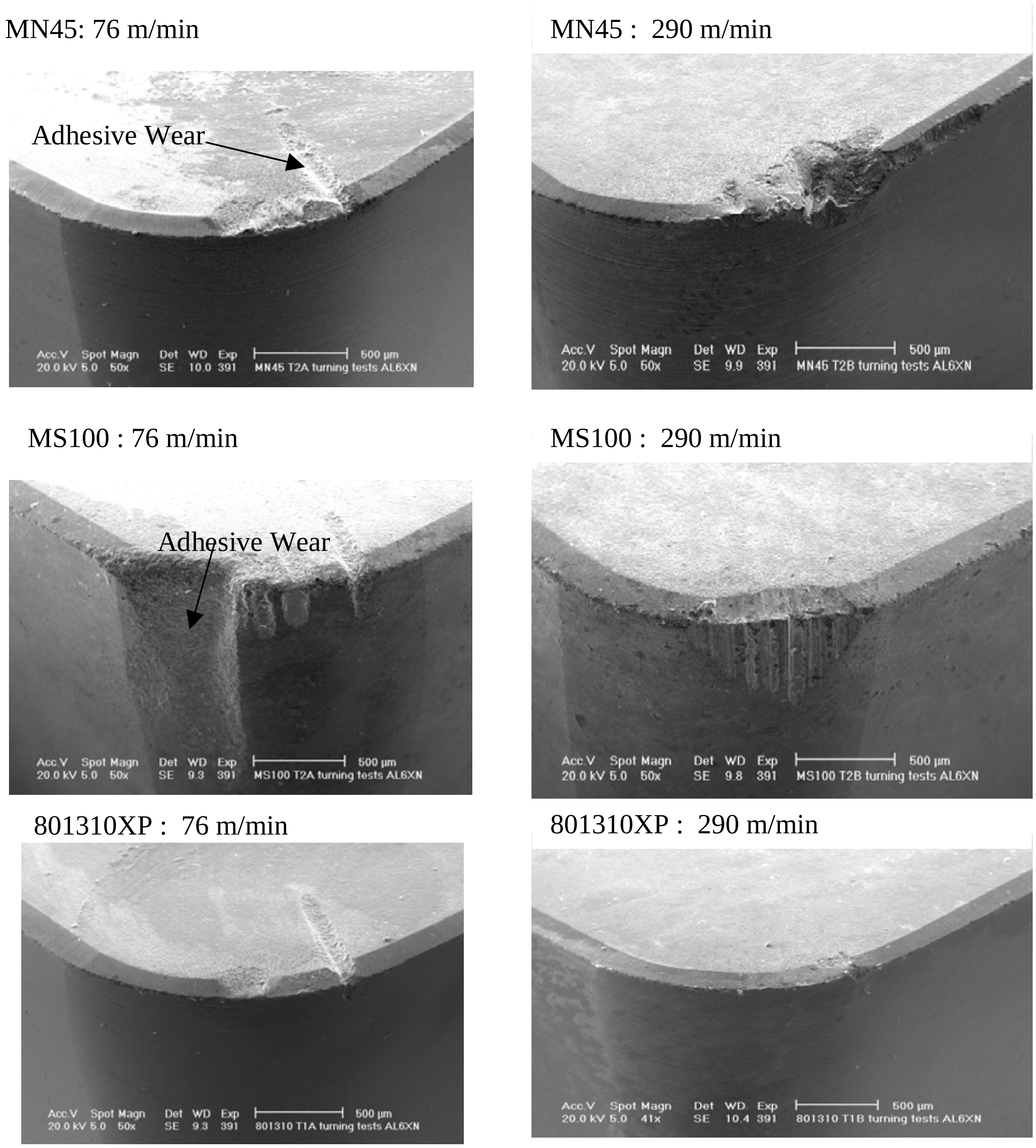

Figure 4 Lathe machining insert wear comparison for different PCBN grades.

Figure 5 shows FSP tool wear for all three PCBN grades tested after a total of 49 minutes processing in AL-6XN. PCBN FSP tools tested in 304L stainless did not show any visible wear and as a result, all FSP tools were tested in AL-6XN. Adhesive wear was most prominent in the MS100 tool. Fractures on the shoulder of the MN100 FSP tool are likely due to crack initiation sites initiated from adhesive wear locations. Further study is required to further understand this failure mechanism. The MN45 tool showed a build up of AL-6XN material in the shoulder region and the presence of rapid mechanical wear. The groove at the tip of the MN45 FSP tool could be related to accelerated mechanical wear due to chipping during tool fabrication. The 801310XP tool showed overall better resistance to the three main wear modes previously identified.

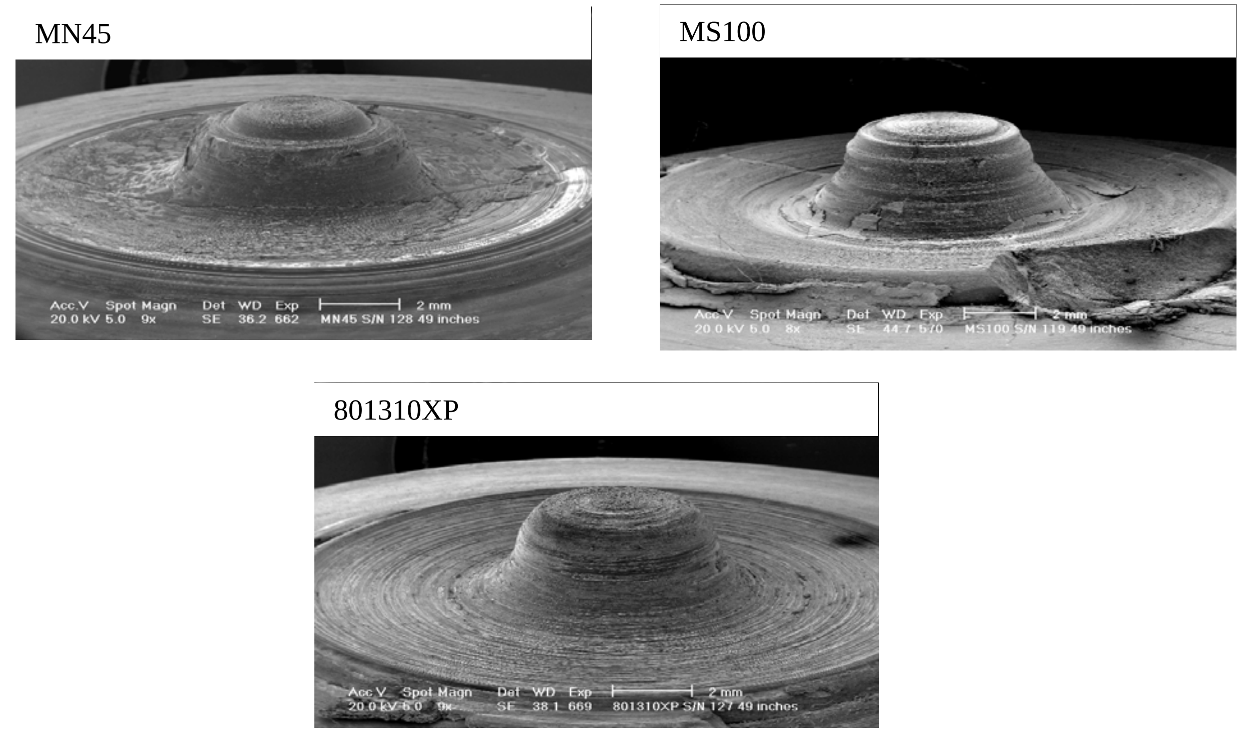

Figure 5 Macro wear comparison of PCBN grades following 49 minutes of FSP testing in AL-6XN.

Figure 6 shows a wear mode correlation between machining inserts and PCBN tools on the MS100 PCBN grade. Significant adhesive wear caused “pullout” of PCBN matrix material both in the cutting tool (ref. top right photo) and the FSP tool (reference bottom photo). The adhesive wear mechanism is more prominently seen on the FSP tool pin and correlates directly to the slower (“cooler”) speeds of the lathe turning tool. However, the shoulder of the MS100 tool shows significant mechanical (abrasive) wear that is directly correlated to the wear mode most prominent in the faster machining speeds (ref. top left photo). There was no evidence of diffusion wear in either the PCBN inserts or FSP tools. A comparison of the MN45 and 801310XP grades with respect to wear modes in machining inserts and FSP tools yields similar results; i.e., a correlation between failure mechanisms for machining versus FSP has been demonstrated for all three PCBN grades.

Conclusions

PCBN machining insert wear mechanisms correlate directly with PCBN FSP tool wear mechanisms. Machining tests in AL-6XN can be used as a screening method to determine PCBN FSP tool performance relative to other PCBN grades. By modifying PCBN grade properties through altering parameters such as cBN content, second phase type / content and grain size, PCBN grades can be tailored for improved PCBN FSP tool performance in AL-6XN. PCBN grades designed for optimum cutting tool performance, are expected to provide the best performance during FSP of the same material.

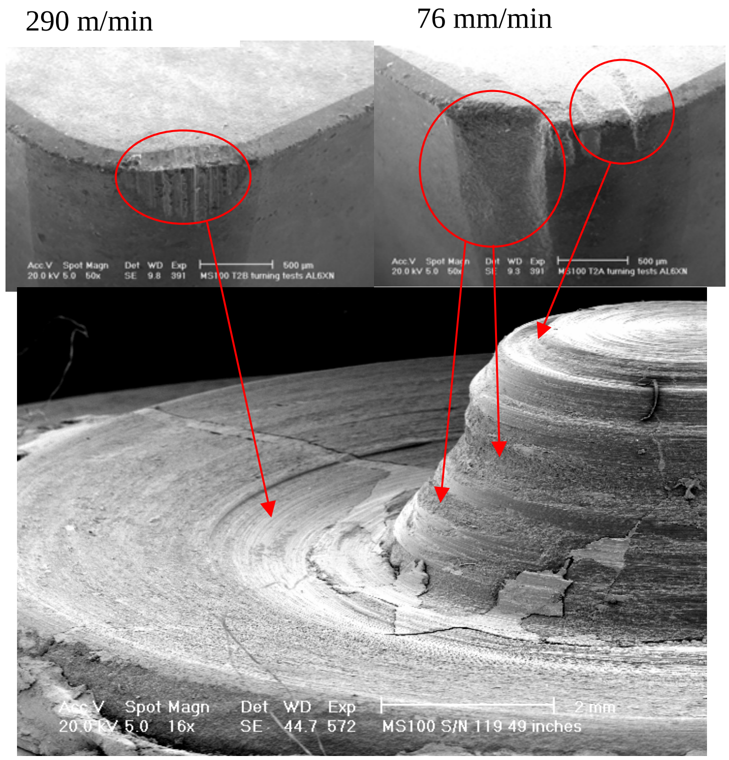

Figure 6 Correlation of wear characteristics found in cutting inserts v/s FSP tools for PCBN grade MS100.

Acknowledgments

The authors acknowledge financial support for this work from the Defense Advanced Research Projects Agency (DARPA) contract NO. MDA972-02-C-0030 and Dr. Leo Christodoulou, Program Manager; and NSWC Carderock Division as Program Monitor. The authors also acknowledge Mr. Murray Mahoney from RSC for review of the manuscript.

References

[1] M. Mahoney, R.S. Mishra, T. Nelson, J. Flintoff, R. Islamgaliev, and Y. Hovansky, *Friction Stir Welding and Processing*, TMS Indianapolis, Nov. 4-8, 2001, pp. 183-194.

[2] M.P. Miles, M.W. Mahoney, T.W. Nelson, and R.S. Mishra, to be published in the TMS San Diego Proceedings *Friction Stir Welding and Processing II,* March 2003.

[3] Z.Y. Ma, S.R. Shaarma, R.S. Mishra, and M.W. Mahoney, published elsewhere within these proceedings.

[4] S.P. Lynch, D.P. Edwards, A. Majumdar, S. Moutsos, and M.W. Mahoney, published elsewhere within these proceedings.

[5] P.B. Berbon, W.H. Bingel R.S. Mishra, C.C. Bampton and M.W. Mahoney, Scripta Mat., vol. 44 (2001), p. 61.

[6] C.J. Sterling, T.W. Nelson, C.D. Sorensen and M. Posada, published elsewhere within these proceedings.

[7] C. Fuller, M.W. Mahoney and W.H. Bingel, to be published in the Proceedings of the Fourth International Symposium on Friction Stir Welding, Park City, UT, May 2003.