

Design, Characteristics and Performance of Diamond Pad Conditioners

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ABSTRACT

A wide range of diamond pad conditioner (disk) designs have been characterized and key performance metrics have been collected. Relationships between design characteristics including diamond size and shape, spatial density, and tip height distribution and polishing pad wear rates and pad surface textures have been established for a variety of pads.

Estimation of the depth-of-penetration of working diamonds, from used disk analyses, allows meaningful topographic assessments of alternative conditioner designs and predictions of relative performance. An example of an improved conditioner that illustrates this design methodology is given.

Conditioner aggressiveness and its decay in various slurries have been measured to assess disk lifetime in Chemical Mechanical Planarization (CMP) processes environments. Key factors affecting disk lifetime are discussed and an improved-lifetime conditioner for use in aggressive slurries will be reviewed.

INTRODUCTION

Diamond pad conditioners are used to prepare and maintain the surface of polishing pads used in CMP processes. The process advantages provided by proper pad conditioning have been reviewed elsewhere and include improvements in polishing rate and stability, planarization, and defectivity. [1]

Key performance attributes of diamond pad conditioners are cut and finish, similar to many other abrasive products. What is rather unique, compared to other abrasive processes, is that the workpiece (the CMP pad) is used in a subsequent (or concurrent) polishing process, and needs to possess very specific attributes for optimal performance.

CMP pad choices have evolved beyond the basic hard porous pad to include those developed for more specialized applications. Formulations are now available that include softer pads and finer pore structures for improved defectivity with copper and advanced low-k dielectric materials, more-durable pads for improved life, and solid pads. Conditioning requirements for these new classes of CMP pads have driven the evolution of new pad conditioner designs. Slurry choices have also evolved and influence conditioner selection for a particular application.

DISCUSSION

Pad Conditioner Design Space

A useful concept to understand different classifications of pad conditioners is Design Space, which conveys the location of a particular disk design in terms of its two key performance attributes; finish and aggressiveness. These attributes describe the surface finish and also the aggressiveness or cutting ability that the conditioner imparts on a reference pad material. Both

are measured using standardized test conditions and correlate well with analogous measurements on various CMP pads. Surface finish and aggressiveness of several conditioner types are shown in Figure 1.

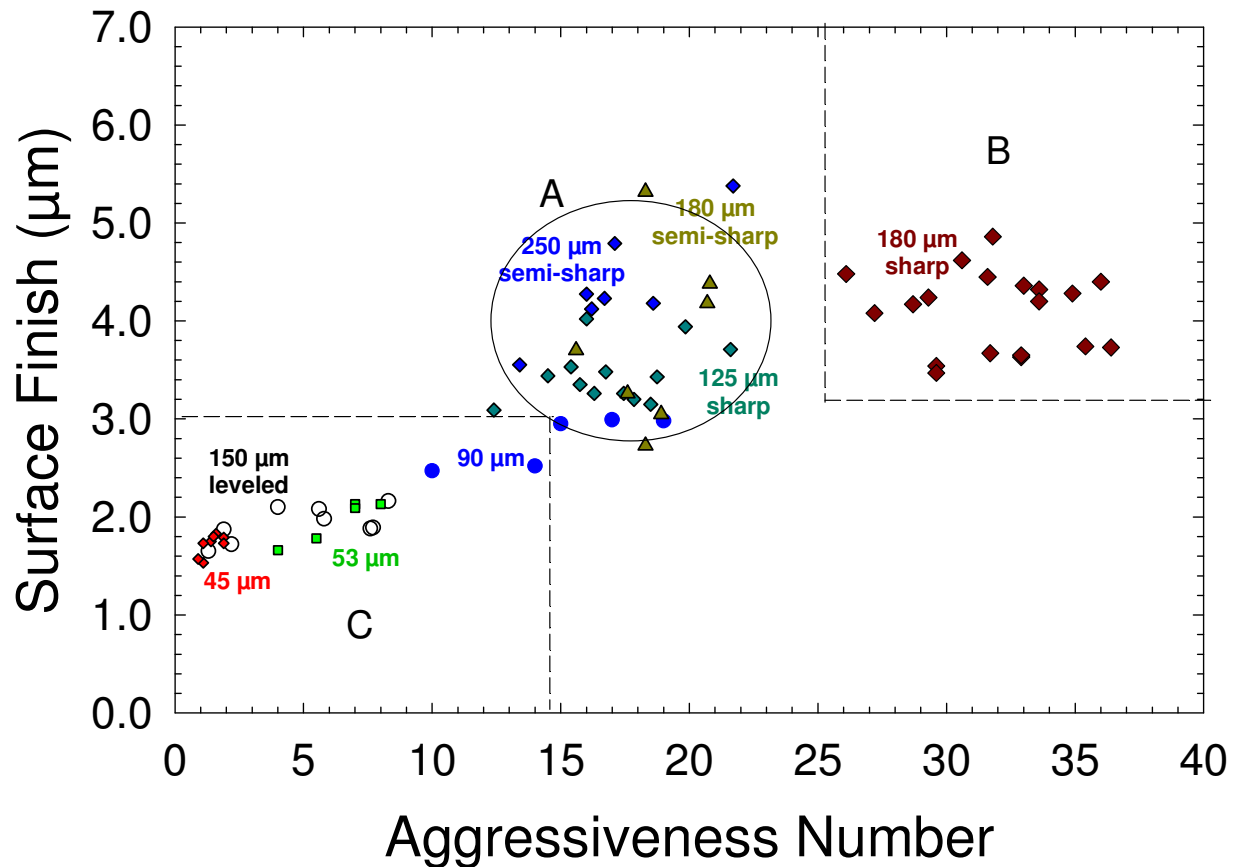


Figure 1. Surface finish and aggressiveness map for a variety of pad conditioner designs

First-generation disks were made using 250 μm semi-sharp diamonds. Their finish and aggressiveness tended to fall in the center of the map (region A). These designs work well in 200 mm processes that use industry-standard hard, porous CMP pads. Second-generation pad conditioner designs incorporated improvements in flatness and also utilized smaller-sized diamonds, which shifted both finish and aggressiveness to lower values.

With the introduction of 300 mm processes, conditioning requirements became more demanding, primarily due to the larger pads used. In this case, first-generation conditioners may not provide adequate lifetime to provide for multiple pad changes. This situation is even more-challenging if an aggressive slurry is used. By this, we mean a slurry that wears the diamonds on the conditioner at a relatively rapid rate. In order to improve conditioner lifetime, designs are needed in which the disk aggressiveness degrades at a slower rate. As seen in region B of Figure 1, these disks have increased aggressiveness over the first generation disks.[2]

New conditioner designs that utilize smaller sharp diamonds (region A, 125 μm sharp) show improved removal rates in tungsten polishing applications. Besides their use in aggressive

slurries, these designs are also finding application on CMP pads that have more demanding conditioning requirements.

Fine-finish pad conditioner designs tend to be in the lower left region of the map, as seen in region C of Figure 1. The need for this class of conditioners is driven primarily by new CMP pad formulations, as described below. In general, a finer pad finish can be obtained by using a conditioner with smaller diamond sizes. However, there are practical limits to reducing diamond size in pad conditioners. We have also developed fine-finish conditioners by improving the diamond tip height distribution. Such an example is illustrated by the 150 μm leveled design in region C of Figure 1.

The design space concept has proven very useful. Plotting the attributes of a particular disk in this way allows one to select a new design for a particular application based on its desired performance attributes or its location relative to an existing design.

Improvements in Fine-Finish Disk Design

Advanced-node (90 nm and less) CMP processes have driven improved pad designs. An important aspect of these improved pads is the ability to design the pad properties to fit specific CMP needs [3]. Compared to first-generation pads, newer generation pads may contain smaller and lower volume of pores. In order to preserve the native porosity distribution, these pads require a conditioner that imparts a finer surface texture [4]. Other pad designs can reduce scratch counts when low cutting rates are employed which generate less pad debris [5]. Some of these advanced pads require conditioners which are in the “fine-finish” region of the design space (region C of Figure 1).

One of our fine-finish disk designs, which utilizes small-sized diamonds, has been used successfully in a high-volume production environment. However, occasional wafer defect issues have been reported with this design in state-of-the-art copper polishing nodes. Post-use examination of suspect conditioners has provided valuable information regarding potential root causes of the defects and allowed for the development of an improved design which addresses these issues. Post-use examination of conditioners also provided information regarding the depth-of-penetration (DOP) of the working diamonds into the CMP pad. By locating and measuring the absolute elevations of worn diamonds, it was determined that the estimated DOP during use was approximately 15 μm . This information provides a meaningful scale in which to evaluate the current and improved disk designs.

Investigation of the surface topography of the current disk design revealed a bumpy texture in the final sintered product, as shown in the 1 cm^2 area topography scan in Figure 2a. The topography irregularities may contribute to defects during the CMP process.

A new design significantly improved the disk topography. A slightly-larger diamond size provided for improved diamond protrusion. A slightly-blockier diamond grade minimized the increase in pad wear rate (PWR) that was expected to accompany the increase in diamond size. PWR and surface finish of the disk were further optimized by improving the diamond tip height distribution. The surface topography and estimated contact area of the new design is shown in Figures 2b and 3b, respectively. With the new design, a significant increase in the number of working diamonds is observed at a 15 μm elevation, Figure 3b. Figure 4 compares two-dimensional surface profiles of the current and new fine-finish conditioners and illustrates the improvements in flatness and diamond height distribution.

The fine-finish disk design improvements were validated by polishing experiments. The current and improved design conditioners were compared by polishing blanket 200 mm copper wafers on an AMAT Mirra Mesa platform. The improved conditioner design provided similar removal rates and improved defect performance over the current design. Copper blanket wafer defect results are summarized in Table I.

Table I. Defect results from blanket copper wafer polishing.

	SP1 micro-defect count	SP1 macro-defect count
no conditioning	88	54
no conditioning	129	57
current design	75	3
current design	67	3
improved design	9	0
improved design	0	0

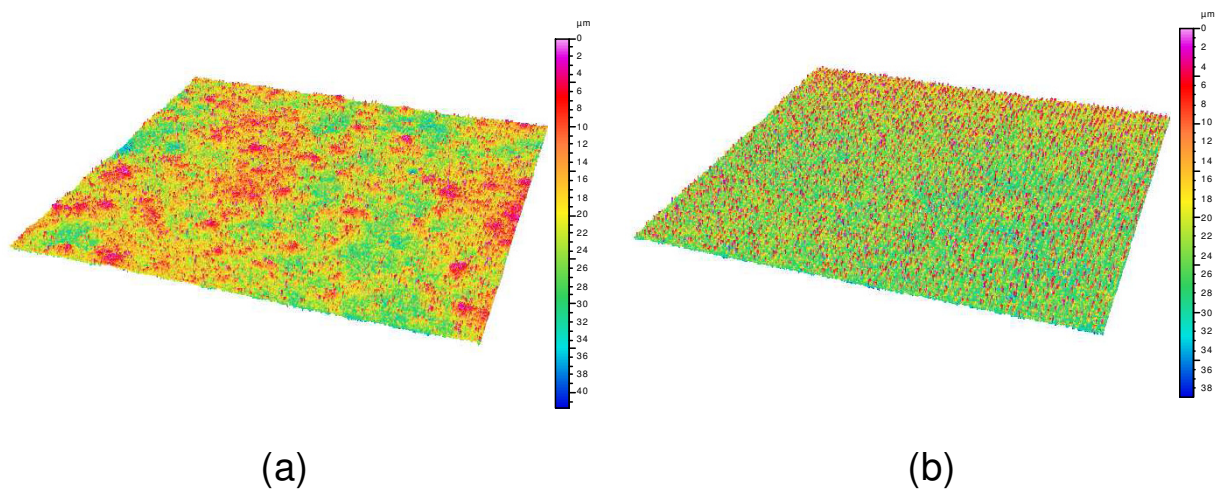


Figure 2. 1 cm² area scans comparing disk topography of a) current and b) improved fine-finish disk designs.

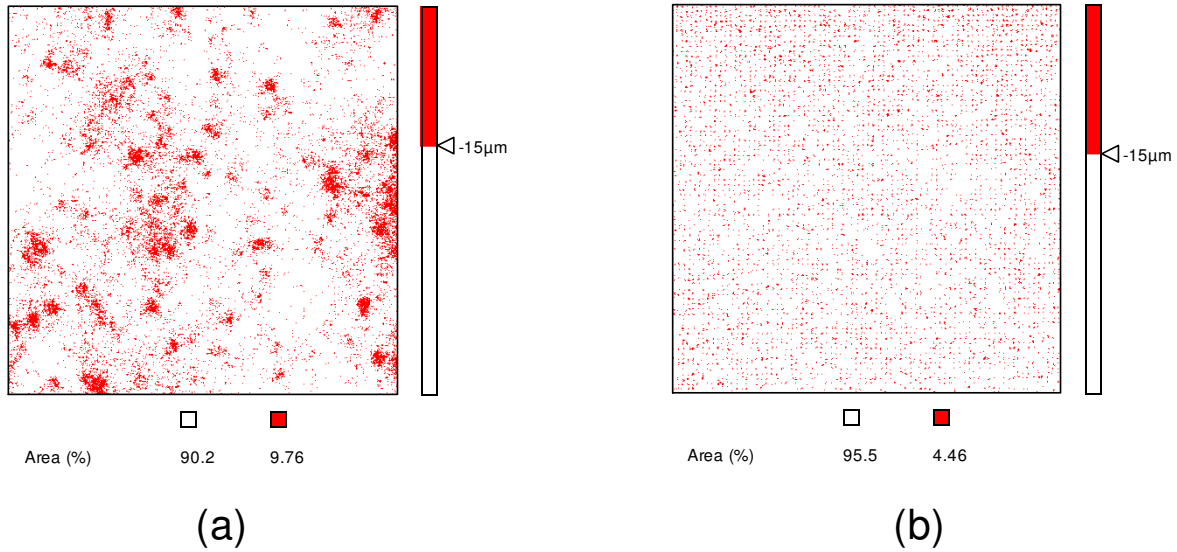


Figure 3. Surface topography slice at 15 μm elevation showing estimated contact area of the a) current and b) improved fine-finish disk designs.

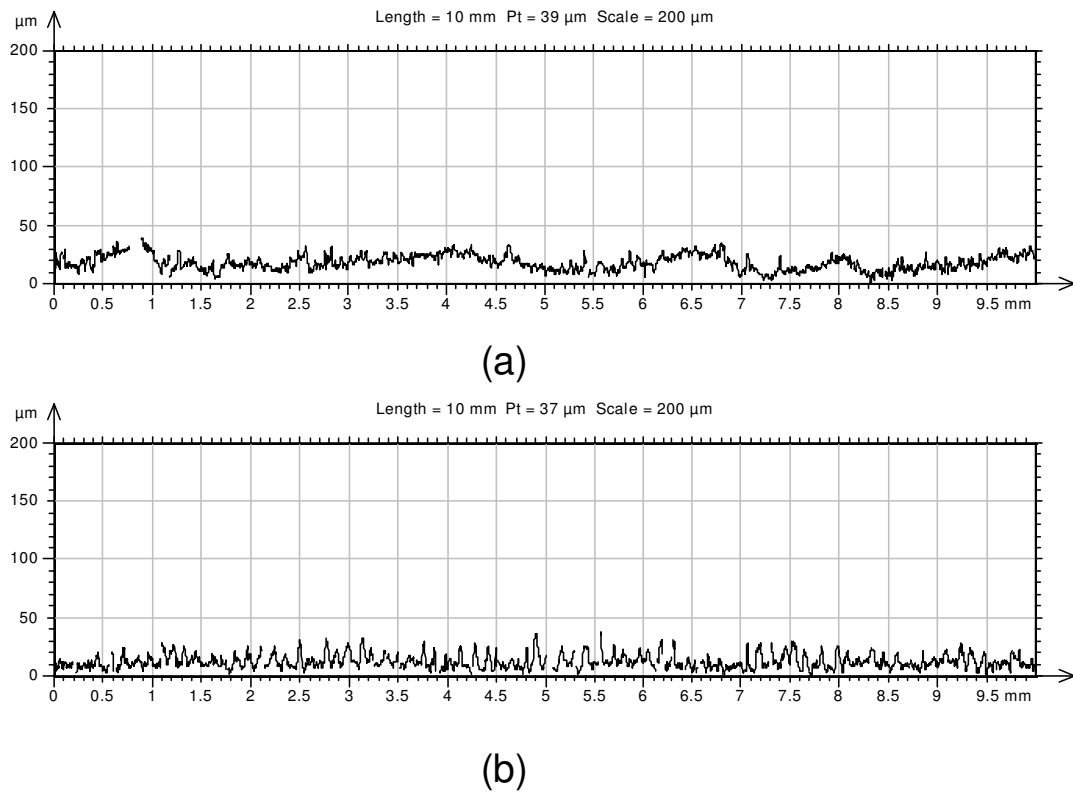


Figure 4. Surface profiles showing flatness of a) current and b) improved fine-finish disk designs.

Effects of Slurry on Conditioner Lifetime and Performance

Pad conditioning is just one of the dozens of process variables that affect CMP performance [6]. Control and stability of the conditioning process depends not only on the initial performance of the diamond pad conditioner, but how that performance changes over time. This change is primarily due to wear of the diamonds.

In the context of conditioner life, it is important to understand how slurry affects diamond disk performance. There are additional variables in a given CMP process that affect conditioner life, such as platform (200 versus 300 mm), conditioning type (in-situ versus ex-situ) and cycle (100% versus 50%), platen and conditioner rotational speeds, CMP pad type, etc. In this paper, we will focus on the effect that slurry has on conditioner life.

We evaluate conditioner lifetime with an accelerated life test, which utilizes in-situ conditioning on a Strasbaugh polisher to subject the diamonds on the conditioner to the same physical and chemical environment they encounter on wafer CMP tools. At the beginning of the test and at selected intervals during the test, the conditioner is removed and its aggressiveness is measured using a 3M standardized aggressiveness test. At the same time intervals, the CMP pad thickness is measured on the polisher. In this way, both the pad cut rate and the conditioner aggressiveness are monitored as a function of conditioning time.

This accelerated life test was used to evaluate several different slurries on a baseline conditioner design (3M A160 Diamond Pad Conditioner). Figure 5 shows the total pad wear of an IC1000 pad after 3 hours of testing. The data are grouped into slurry families (W, Cu, Oxide) and sorted from highest to lowest within a family. A pad wear test of the same conditioner design using only DI water gives a total cut of about 4.2 mils in 3 hours under the same test conditions. Within a slurry family, a range in pad wear of about 2x can be observed. In general, pad wear is lowest in tungsten slurries. As a family, tungsten slurries tend to cause the most-severe diamond wear on the conditioner. With both copper and oxide slurries, pad wear can be either higher or lower than is observed when conditioning in DI water. The resulting pad wear depends on the balance between how aggressive the slurry is at wearing the diamonds and how effective the slurry is at wearing the pad.

Pad conditioner design can be modified to counteract this aggressive wear and extend the disk lifetime. Figure 6 shows pad cut rates during an accelerated life test for various-sized sharp diamond conditioners that were tested in tungsten slurry that tends to aggressively wear diamonds. As seen in Figure 6, all three of the sharp-diamond conditioners had cut rates that were higher and decayed at a slower rate than that of a competitive disk. After 6 hours of testing, the competitive disk retained only about 15% of its initial cut rate whereas our sharp-diamond disks retained between 55 and 65% of their initial cut rates. These sharp-diamond conditioners provide about twice the lifetime as the competitive disk, determined by when the pad cut rate drops below a minimum value (shown by the horizontal dashed line in Figure 6).

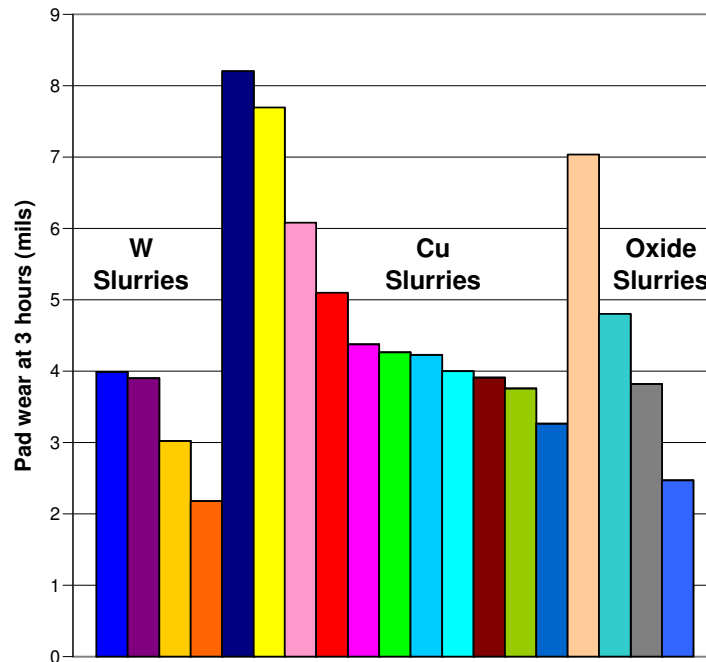


Figure 5. Total pad wear after 3 hours of accelerated life testing in various CMP slurries.

Although pad cut rate (and its decay with time) is a key property to consider when selecting a conditioner for use in aggressive slurries, other factors may influence the selection. Some CMP pads may benefit from more aggressive conditioning, regardless of the slurry. [7]. Recently, we have observed improved tungsten removal rates when smaller-sized sharp diamond conditioners are utilized. This is consistent with published results that show a correlation between tungsten removal rates and pad texture (finer texture giving higher rates) [8].

CONCLUSIONS

The concept of a Pad Conditioner Design Space is useful to understand different classifications of diamond pad conditioners. It conveys the location of a particular disk design in terms of its two key performance attributes, finish and aggressiveness, and facilitates the selection a disk design for a particular CMP application.

Post-use examination of conditioners provides information regarding the depth-of-penetration (DOP) of the working diamonds into the CMP pad. A new design with improved surface topography characteristics was developed which exhibits improved polishing performance.

Conditioner aggressiveness and its decay in various slurries have been measured. Disks have been developed that exhibit improved lifetimes in aggressive slurries.

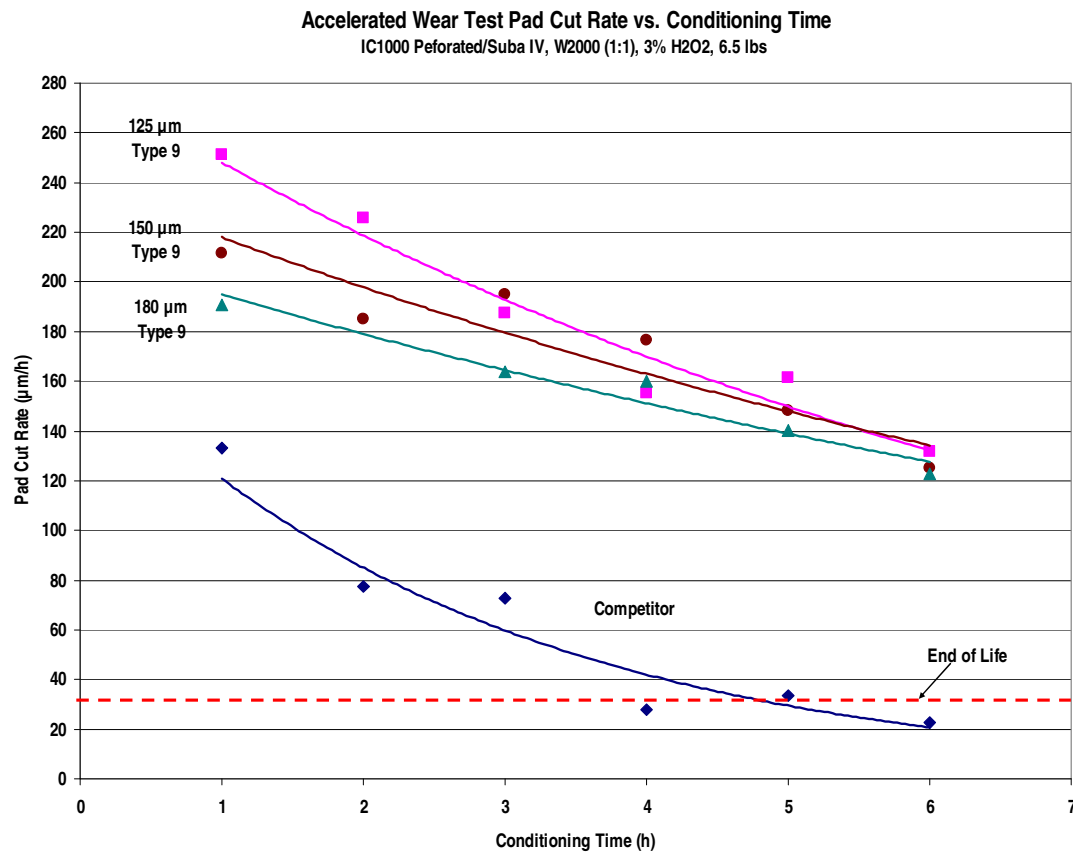


Figure 6. Pad cut rate decay curves during accelerated life testing in tungsten slurry of sharp diamond disks of varying diamond size (125, 150 and 180µm).

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REFERENCES

1. A.S. Lawing, CMP-MIC 33-42 (2005).
2. T. Engfer, B. Goers, A. Zagrebelny, L. Zazzera, 12th International Symposium on CMP (CAMP) (2007).
3. T. Kasai, C.W. Nam, S. Li, J. Kasthurirangan, W. Fortino, Y. Homma, S. Tanaka, A. Prasad, G. Gaudet, F. Sun, A. Naman, ICPT, 91-96 (2009)
4. A. S. Lawing and C. Juras, ICPT, 25-30 (2007)
5. S. Kamo, H. Miyauchi, H. Shida, ICPT, 279-284 (2009).
6. G. Banerjee and R. Rhoades, ECS Trans., **13** [4] 1-19 (2008).
7. F. Sun, J. Hawkins, J. Tsai, G. Chiu, A. Naman, ECS Trans., **18** [1] 517-522 (2009).
8. M. Akaji, S. Haba, K. Yoshida, A. Isobe, M. Kinoshita, ICPT, 97-102 (2009).