New approach for pre-polish grinding with low subsurface damage

James B. Johnson, Dae Wook Kim, Robert E. Parks, and James H. Burge

Large Optics Fabrication and Testing(LOFT) Group, College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA

ABSTRACT

For an optical surface to be properly prepared, the amount of material removed during polishing must be greater than the volume of grinding damage. An intermediate stage between loose abrasive grinding and polishing can reduce the total volume of subsurface damage. This results in less time and expense needed during the polishing phase. We have characterized the Prestos's coefficient and subsurface damage depth for 3M Trizact$^{\text{TM}}$ diamond tile pads and believe it can fit this intermediary role. Trizact shows a sizeable reduction in the overall subsurface damage compared to similar sized loose abrasives. This understanding of the abrasive behavior allows us to create a better grinding schedule that more efficiently removes material and finishing with less overall damage than traditional loose abrasives.

Keywords: subsurface damage, Trizact, optical fabrication, taper polish, stress lap

1. INTRODUCTION

In an effort to improve manufacturing quality and reduce costs, new methods of grinding and polishing are of interest in the production of large diameter aspheric mirrors. Trizact is an interesting case. It has the potential to give faster removal rates[1,2] while creating shallower subsurface damage (SSD) than loose abrasives.

Due to its properties, it works well as an intermediate grinding stage, before polishing, specifically to remove remaining SSD left behind by generating. Trizact creates very little SSD, reducing the amount of polishing needed. This process is similar to microgrinding,[3] but at a larger abrasive sizes (20-3μm).

This paper presents characterization data of the pad behavior relating to its uses with a stress lap tool on lightweights mirrors. Because of their shape, lightweights mirrors cannot handle large pressures without quilting the surface. Trizact will need to be used in a non-standard way with the stress lap remain effective. With this data, optimal CNC grinding runs can be designed by opticians in crafting the large aperture mirrors.

2. TRIZACT MATERIAL

Trizact diamond tile is a pad-based bound abrasive (Fig. 1a). The diamond particles are contained within a soft polymer matrix (Fig. 1b). The pad continually refreshes itself by wearing the polymer. At a sufficient wear rate, the material ejects worn diamond into the slurry and exposes fresh, sharp diamond at the cutting surface.

Two different varieties of Trizact are available from 3M: larger abrasives(20μm and up) in the 673FA variety and smaller ones in the 677XA series ($< 9\mu m$). Aside from abrasive size, the larger grits come with a thicker fabric-type backing, while the 677XA pads use a thinner and more flexible plastic backing. Both are self-adhesive and stick equally well to the metal or pitch and tile tools frequently used in grinding. The flexibility of the backing allows them conform to curved tooling as well as flats. Contrasted with a diamond grinding disc or wheel, the pads are able to integrate into existing tooling in a similar fashion to other pad like materials(e.g. Pellon, polyurethane). No additional equipment is necessary.

Further author information: (Send correspondence to James Johnson)
Email: jjohnson@optics.arizona.edu, Telephone: 1 408 829 7827

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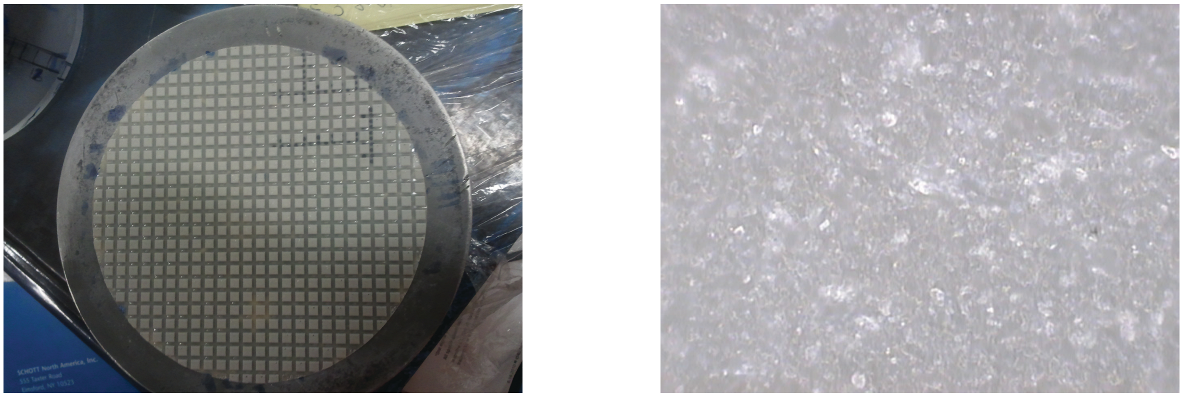


(a) 9μm Trizact diamond tile pad on a stiff tool.

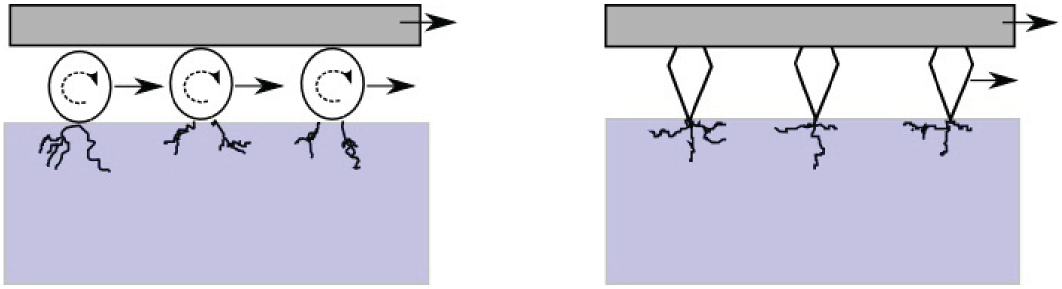
(b) High magnification image of Trizact surface showing bound diamond particles (white).

Figure 1. The Trizact material showing pads and bulk material.

3. COMPARISON WITH LOOSE ABRASIVES

Loose and bound abrasives remove material in different ways. Loose abrasives have three parts to the mechanical process: tool, ground surface, and abrasive (Fig. 2a). The abrasive particles roll freely, creating indentation cracks along the surface.[4,5] As pressure is released, these fractures open up and free the damaged surface material. Because the particles are dull and round, the SSD cracks created below the points of contact are conical and can run deeply.[6,7] Shop practices estimate the depth of SSD to be 1.5[5,8]-3 times the prior abrasive size.

Bound abrasives only use two bodies: the abrasive tool and the ground surface (Fig. 2b). The abrasive repeatedly scratches the surface, removing material along the direction of motion. Fractures run along the surface as well as point fractures located below the tip of the diamond. The shallow, near-surface fractures help remove material as the diamond chips away glass.



(a) 3-body loose abrasive grinding

(b) 2-body loose abrasive grinding

Figure 2. Geometries of loose and bound abrasive grinding.

A major concern with grinding are the SSD cracks that appear below the optical surface. These fractures weaken the bulk material strength of glass and degrade overall optical performance. A purpose of polishing is to eliminate all of the SSD created during the grinding phase.

Trizact works on the glass in a ductile fashion, and it is this property that makes it interesting as a material for manufacturing large optics. The ductile behavior of Trizact indicates it will plastically deform the surface rather than brittly fracture it. Consequently, SSD will not be as deep as loose abrasive particles. If the amount of SSD generated during the final stages of grinding can be reduced, less polishing is needed on the final product. Since polishing has considerably lower removal rates compared to grinding, any reduction in the amount of polishing needed can lead to dramatic cost savings.

A secondary effect of grinding with Trizact is the quality of the final surface. For similar particle sizes, Trizact appears more transparent than loose abrasives. The surface begins to show specular qualities, especially at $3\mu m$, and at shallower angles of incidence for all other sizes.

4. ADVANTAGES OF PRE-POLISHING WITH TRIZACT

Trizact works as an intermediate stage grinding material. Due to the high removal rates and low SSD, it is ideal as a replacement for the smaller loose abrasive grinding stages. Generating and initial figuring work with larger particles. The pads adhere directly to tile, and proper curvature is needed to match the pads to the surface for full contact to be made.

As the part progresses to smaller abrasive sizes ($< 25\mu m$), the benefits of Trizact become cost effective. In the initial grinding with the Trizact, enough material needs to be removed to eliminate the loose abrasive SSD. The high removal rates decrease the time needed at this step. At this point, any SSD will be from Trizact and focus is on piston removal of remaining SSD and small corrections to the figure.

4.1 MEASUREMENT OF REMOVAL RATE

To measure the removal rates of Trizact, a grinding spindle machine was setup with similar properties to a 1m stress lap. These laps operate at lower speeds and pressures than are recommended for use with Trizact pads. In this case, the stress lap runs at $0.3psi$ with a peak linear speed of $0.45m/s$.

Testing focuses on the 20, 9 and $3\mu m$ Trizact pads, which fall into the pre-polish zone for SSD . The machine is also configured for similar sized loose abrasives with a cast iron tool to make direct comparison. All tests are done using 4" Borofloat workpieces. Detailed parameters are presented in Table 1.

Table 1. Parameters for removal rate tests.

Parameter	**Trizact 20μm**	**Trizact 9μm**	**Trizact 3μm**	**Loose abrasives (25,12,5μm)**
Tool diameter (mm)	100	100	100	100
Tool pressure (psi)	0.27	0.31	0.38	0.30
Part diameter (mm)	100	100	100	100
Average linear speed (m/s)	0.413	0.413	0.413	0.413
Slurry mixture	$5\mu m$ abrasive	$5\mu m$ abrasive	$5\mu m$ abrasive	N/A

Removal rates will vary depending on the roughness of the starting surface. Each test has an initial surface ground to one abrasive size larger. This will model similar conditions to what the pads are likely to see during use.

Due to the low speeds and pressures, the Trizact pads are unable to wear properly. Too little diamond is ejected from the binding into the slurry to wear the binding fast enough. A 1% solution of $5\mu m$ abrasive is added to the slurry to continually refresh the pad.

Removal volume was measured by coordinate measuring machine(CMM) with a ball probe to create a linear surface profile. The difference between initial and final profiles can be calculated giving the radial removal profile. From this, the total volume of glass can be calculated by integration.

The stress lap, along with other machines like orbital grinders, will run under very different speeds and pressures depending on the strokes designed by the opticians. A neutral parameter for measurement, the Prestons's coefficient,[9] is ideal for establishing a number that will work across varied parameters.

The data in Fig. 3 shows Trizact removing 1.5-3 times the material that similar sized loose abrasives do. This provides a faster convergence in the computer controlled optical surfacing(CCOS) process.

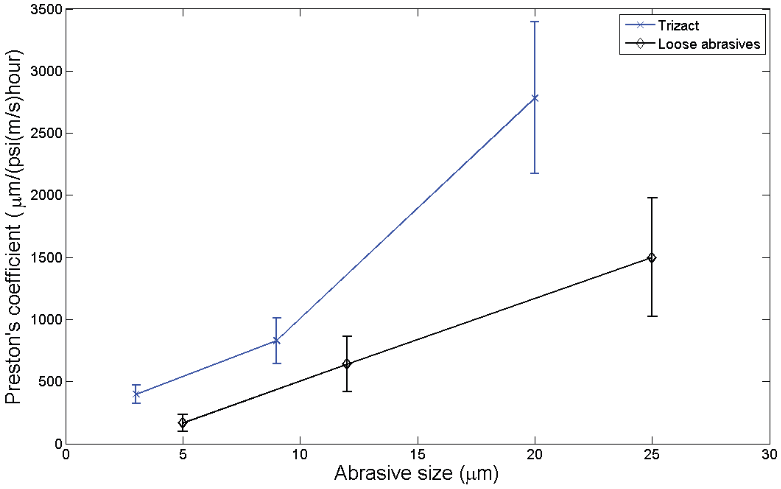


Figure 3. Prestos's coefficients of various loose and bound abrasive grinding materials.

4.2 SUBSURFACE DAMAGE MEASUREMENTS

Subsurface damage for each of the Trizact pads is also measured. The glass is prepared by grinding with one size larger abrasive until a uniform surface texture is present. Twice that abrasive size was then removed with the pad under test. The surface is polished using a 1" flat tool to create a removal taper. LP66 and rhodite are used as the polishing compounds.

A CMM removal profile is created (Fig. 4) to determine the depth at a given radius. Then, SSD measurements, as a function of taper depth, are made using a WYKO NT-2200 white light interferometer(WLI) with a 2.4mm FOV objective.

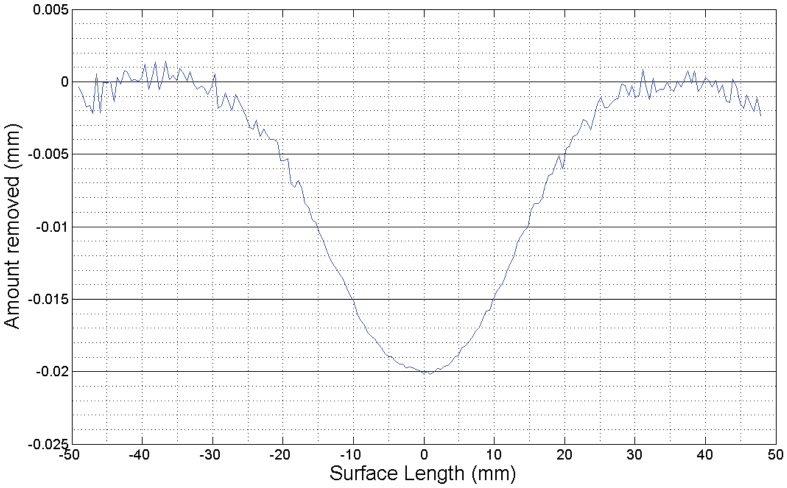


Figure 4. Taper polish removal profile after 180 minutes on a 9um Trizact sample.

Trizact damage appears in the form of scratches across the surface (Fig. 5). The number of scratches are measured at various depths along the taper to create a SSD distribution profile and to estimate the overall depth of the SSD.

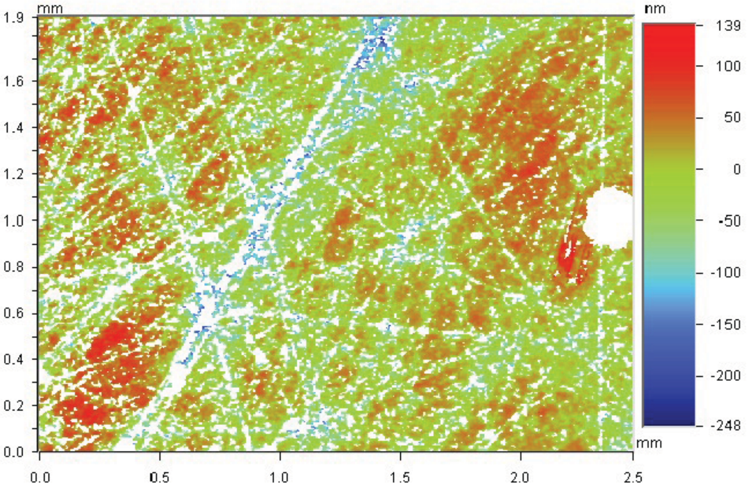


Figure 5. Trizact damage from a 20um Trizact surface with 0.5um removed (Rq = 37.6nm).

Table 2. Maximum SSD depth for various Trizact abrasives.

Abrasive size (μm)	**Maximum SSD depth** (μm)
Trizact 20 μm	20 μm
Trizact 9 μm	10 μm
Trizact 3 μm	4 μm

Data in Table 2 shows the SSD depth to be no more than 1.1 times the Trizact abrasive size. This is a significant decrease from SSD estimates for loose abrasives. The SSD distributions(Fig. 6) for scratches within a unit area follow an exponential decay with depth[7] and appear linear when plotted on a log-log scale. The statistical nature of this distribution curve indicates the improbability of eliminating 100% of the damage over any surface. A depth point can be selected where the likelihood of remaining SSD is improbable. As with scratch/dig specs, this scratch per unit area metric is purely cosmetic. Yet, it accurately reveals the quality of surface in how free from remaining damage it will be.

Smaller abrasive sizes add to the pre-polish advantage. Typically grinding on large mirrors does not occur with abrasives smaller than $9\mu m$ due to the increased probability of large scratches caused by the tool. With Trizact, the tool is separated from the surface by the polymer. This separation extends the margin of safety in reducing potential collisions. No significant increase in scratching is seen at the $3\mu m$ size.

Shallower SSD present in the glass reduces the amount of polishing required. Compared to grinding, polishing is a slow process and any reduction in the amount required is valuable. As little as $4\mu m$ of polishing is needed on a surface ground with $3\mu m$ Trizact. The time savings, due to elimination of SSD in the final ground surface, makes Trizact extremely cost efficient for large optics.

4.3 A PRACTICAL EXAMPLE FOR TRIZACT PRE-POLISHING

Consider the case of grinding a 4m lightweight mirror with a 0.5m stress lap. Assuming an ideal figure is generated, a piston removal of the SSD is needed to finish the surface. A typical grinding schedule would progress from generating to $60\mu m$, $40\mu m$, $25\mu m$, and finish with $12\mu m$ abrasives before moving to the polishing stage. During each abrasive step, the amount of material that must be removed is equal to the SSD of the prior abrasive size. So for $25\mu m$ loose abrasives, $60\mu m$ deep of grinding is required due to the prior $40\mu m$ abrasive creating a minimum of 1.5 times the abrasive size in SSD. Therefore, the total volumetric removal is the cylindrical volume encompassing the size of the mirror multiplied by the SSD depth.

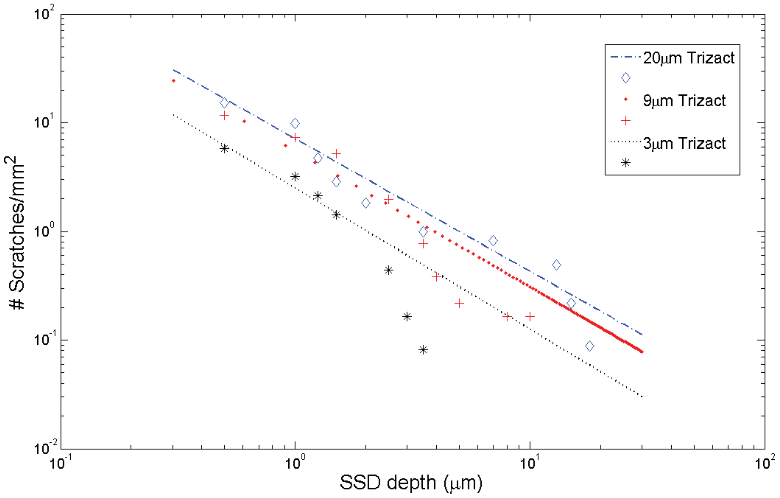


Figure 6. SSD depth distribution for various abrasive sizes.

Manufacturing time for the mirror can be compared between Trizact pre-polishing and loose abrasive processes. If the stress lap runs at $0.3psi$ and with a feed rate of $0.41m/s$, a combination of removal rates and SSD produced at each abrasive size are used to predict a total grinding time for each method. Each method starting at the 25 or 20 μm sizes with SSD produced from the $40\mu m$ grinding.

Fig. 7 shows the results of this comparison. In total, 25% less grinding is needed for the Trizact pre-polish process even though it progresses through an additional abrasive step. Furthermore, the Trizact leaves only $4\mu m$ of SSD rather than the $14\mu m$ of SSD from loose abrasives. This results in 70% less polishing required on the final surface to eliminate any remaining damage.

If the $5\mu m$ step is added to the loose abrasive method, grinding with Trizact becomes almost 60% faster, but only 40% less polishing is needed. In either case, the Trizact advantage is clear.

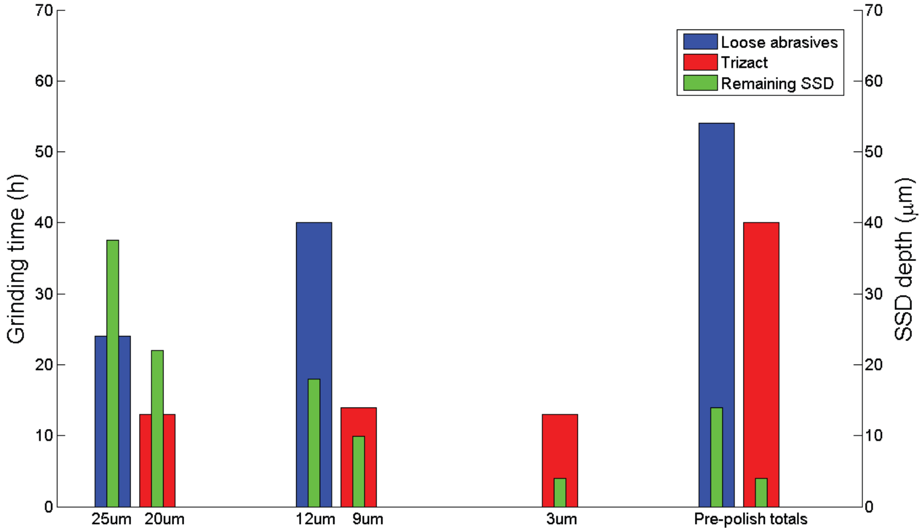


Figure 7. Comparison of grinding times and final SSD depths for loose abrasives and trizact on a 4m mirror.

5. CONCLUSIONS

Pre-polishing with Trizact is an efficient method for producing large scale optics with stress lap tools. Even operating outside of the recommended parameters, the pads produces significant improvements over loose abrasives, producing parts faster with less subsurface damage. Each Trizact abrasive size has a Prestos's coefficient nearly twice that of a similar sized loose abrasive. Subsurface damage is also diminished, at only 1.1 times the abrasive size. Further, the grinding process can advance to smaller abrasives than typically possible for large optics without the large scratching of loose abrasives.

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