



A REVIEW OF SELF-SHARPENING MECHANISMS OF FIXED ABRASIVE TOOLS

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ABSTRACT

Abrasive machining methods are used in machining of precision components with stringent size and surface quality constraints, such as medical devices and automotive components. Depending on the work material, grinding wheels made out of different abrasives like, aluminium oxide, CBN or diamond, removes material in the form of micron sized chips. During machining, the abrasives undergo wear and lose their cutting ability. Subsequently, the performance of abrasive tools deteriorates over time without reconditioning of the tool. As a result, controlled removal of abrasives and/or its bonding materials are crucial mechanisms to be addressed in reconditioning of fixed abrasive tools. So, this article reviews the mechanical, electro-physical and chemical material removal mechanisms and their role in self-sharpening of fixed abrasive tools which pave the way for sustainable machining process.

Key words: Wheel Dressing, Fixed abrasives, Grinding, Electro-physical and Chemical, Self-sharpening

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1. INTRODUCTION

Fixed abrasive machining plays a vital role in generation of high quality surfaces in terms of form and finish along with better surface integrity. It often refers to machining processes which utilize hard abrasive particles held by soft binders as cutting tools, like honing, grinding, etc. [1-2]. While grinding, the tiny chips produced are flushed away by a coolant used in the process, though some of them get entangled into the pores of the wheel. Over a period of time after grinding, the wheel gets loaded with chips and loses its cutting ability. Therefore, wheel conditioning is essential to sustain as an efficient material removal process [3]. Grinding wheel conditioning pertains to the regeneration of abrasive wheel topography and is performed by dressing and cleaning processes. Wheel dressing consists of two distinct activities, namely truing and wheel sharpening. Truing refers to correction of wheel geometry and wheel sharpening is concerned with forced removal of dulled abrasive grains.

Depending upon the bonding medium, work material, surface quality requirements and the choice of abrasives, different wheel dressing mechanism is observed. It can be classified into

mechanical and non-mechanical types based on the nature of material removal from the wheel [4]. In the mechanical type of dressing mechanism, the worn out abrasives are removed from the wheel solely by grinding/external forces which may rupture the bond or the grain or both. This may require the wheels to have sufficient porosity and low strength (soft bond). Under situations when the bond material is sufficiently hard to resist the grinding force (as in metal bonded wheel or hard bonded wheels), the strength of the bond is weakened by an external agent, such as electrical or chemical energy and then, the abrasive grains are removed as in the mechanical means. Techniques falling under the second dressing mechanism are termed as non-mechanical type. Figure 1 shows the classification of material removal mechanisms in self-sharpening of fixed abrasive tools.

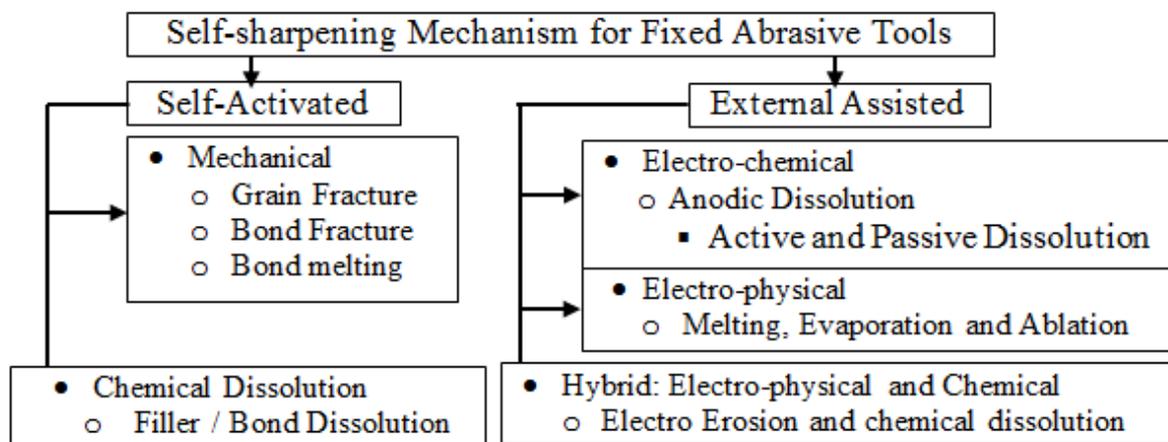


Figure 1 Classification of material removal mechanism in self-dressing process

2. SELF-SHARPENING MECHANISM - SELF ACTIVATED

The self-activated, self-sharpening mechanisms accomplishes dressing along (simultaneously) with the grinding operation. This is achieved either by mechanical or chemical means.

2.1. Mechanical Method

With conventional abrasive wheels like alumina, sharpening is generally performed using a diamond dressing tool. The worn out grains are mechanically removed by applying external force against the wheel periphery and new sharp gains are exposed. This process demands interrupted machining which results in loss of production. By proper choice of the grinding wheel in relation to the work to be machined, the re-sharpening of worn out abrasives happens under the grinding force itself. This phenomenon is termed as 'self-sharpening' of the grinding wheel. This process inherently offers savings in dressing time and achieves overall improvement in productivity. Under mechanical actions, partial fracturing of abrasive grains, bonds and melting of bonding agent are active mechanisms for self-sharpening of fixed abrasive tools.

2.1.1. Grain Fracture Mechanisms

The mechanical forces or thermally induced stresses are the active mechanisms in grain fracture. When the stress exceeds the rupture strength of abrasive material, new cutting edges are created by fracturing away the small portion of the grain giving sharper cutting edges [5-6]. The abrasive grain fracture depends on its friability, which is a characteristic of the abrasive used. Friability is ability of the grain to breakdown into smaller pieces and influences the sharpening of the grains during the grinding process. Small grains having negative rake shapes are less friable than others. Alumina has low friability than Silicon carbide, and so it

has relatively less tendency to self-sharpen. Self-sharpening in Sol-gel alumina wheels are promoted by the micro-fracture of its polycrystalline structure. Further observation reveals that sol gel wheel maintains its cutting ability for longer time than white alumina wheel [7-8].

2.1.2. Bond Fracture Mechanisms

With a worn out wheel, more number of grains engage into sliding and ploughing over the work surface rather than cutting, which increases the grinding force. When the grinding force is in excess of the bond strength, bond fracture and grain fracture leads to the removal of worn out grains and sharpening of the abrasives. The other mechanism responsible for releasing of dull grains by bond fracture is fatigue in nature, due to recurrence influence of mechanical and thermal shock loads during the process. The result is removal of dull grains and exposure of sharp grains in the wheel beneath it [9]. The toughness or wheel hardness has an influence on self-sharpening by bond fracture. The silicate bond releases the abrasive grains more rapidly than the vitrified bond during the process [1, 10-11].

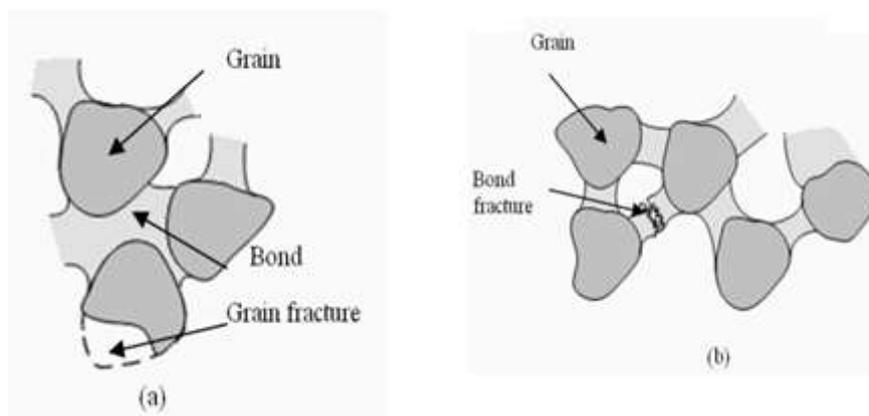


Figure 2 Fracture Mechanism: (a) Grain Fracture and (b) Bond Fracture [11]

2.1.3. Melting of Bonded Material

This kind of mechanism is observed in resin or ice bonded abrasive tools due to their low melting temperature. In this case, melting or phase change of the bonding medium by induced frictional heat during the process is basis for self-dressing of the tool. In resin bonded wheels, the mechanism of softening and melting of thermoplastic resins under heat allows the used abrasives to move with-in the softened bond and are eventually removed from the wheel [12-13]. In ice bonded abrasive tools, melting of the bonding medium into a thin layer of slurry is responsible for ideal, uniform, continuous feed of abrasives to the working zone as well as dislodging the used abrasives. Thus self-dressing of phase changing bonded abrasive exposes new sharp cutting edges. Figure 3 shows typical self-sharpening nature of abrasives in matrix frozen water during process.

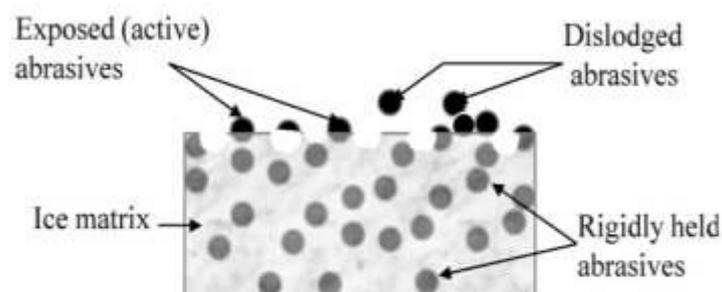


Figure 3 Active and dislodged abrasives in the matrix of frozen water [14]

Initially, Belyshkin had proposed a technique for finishing of glass and crystals using abrasives held the matrix of ice, which eventually melts along the periphery and carries away the chips produced as well as worn out abrasives. Though tool life is short in this case, the process is economic and efficient [15]. Subsequent experimental investigations show that self-sharpening nature of ice bonded abrasive tool enables achievement of nano level surface on copper, stainless steel and titanium alloys without an external tool for dressing [16-17].

2.2. Chemical Dissolution

Self-sharpening by chemical dissolution requires specially prepared abrasive tools whose composition includes a soluble filler material, in addition to abrasives and bonding agents. The soluble filler present in the abrasive tool undergoes a chemical dissolution process when exposed to solvent present in the coolant and thus creates a porous structure on the periphery of the wheel. The relative increase in porosity of the surface layer leads to reduction in strength of the abrasive-bond matrix, giving way for a self-sharpening action under the grinding force. This process has been realized in self-dressing of super abrasive tools having metal/nonmetal oxide fillers. [18]. Figure 4 illustrates the self-sharpening action of metal bonded super abrasive tool embedded with oxide fillers. In another attempt, the self-sharpening characteristics of super abrasive wheel was realized by water swelling mechanism, wherein, the hydrophilic polymer bond under goes swelling action in contact with water molecules and weakens its strength in the vicinity of abrasives. Thus, the weakly bonded abrasives are removed under grinding actions [19]. To maintain high accuracy and durability of the tool, chemical dissolution methods are being investigated.

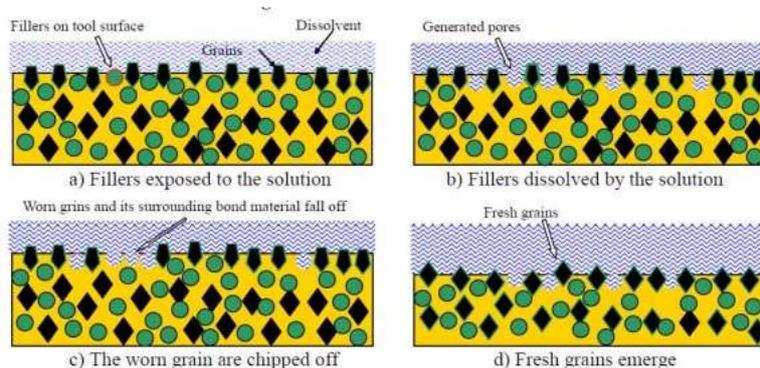


Figure 4 Dressing of porous self-generation super abrasive tool [20]

3. SELF-SHARPENING MECHANISMS – EXTERNAL ASSISTED

In external assisted dressing processes, the controlled removal of the wheel bond by concentrated energy flow is key objective of self-dressing process. i.e., dressing is by bond erosion. The worn out abrasives are dislodged during the grinding process, but prior to it, the strength of its metallic or other hard bond is weakened an electrolytic process, chemical process, thermal process or a combination thereof.

3.1. Electrochemical Dissolution Method

In this method, the self-sharpening of metal bonded abrasive tools is achieved by controlled anodic dissolution due to electrochemical reaction. For this purpose, an electrolytic cell is setup, in which the electrically conductive wheel acts as an anode and a copper cathode is placed adjacent to its periphery, with a certain means of holding the electrolyte in place. Electrolysis process comes into action with the supply of current between the electrodes, giving rise to anodic dissolution of wheel either by forming oxide layer or by ionic exchange.

Thus there are two dissolution mechanisms i.e., active and passive dissolution, available for self-dressing. The activation of either one of the two dissolutions depends upon bond materials, electrolytes and process parameters being employed during the process [21-23].

3.1.1. Passive Dissolution Method

In electrically conductive grinding wheels such as brass, bronze or cast iron bonded wheels, the wheel surface in contact with electrolyte undergoes electrolytic reaction producing a layer of metal oxides and/or hydroxides. The thickness of this layer depends on the circuit current and the dressing time. With the increase of oxide layer thickness, the electrical conductivity of the wheel and the electrolytic current reduces and so the oxide layer is termed ‘passivation’ layer. But under the grinding forces developed in machining, the passive oxide layer is easily removed along with the dull abrasives as they lose their bonding strength. Thus new sharp abrasives are exposed on the wheel periphery and also the anodic dissolution process continues after the brief interruption [24-25]. The application of this process is termed as the Electrolytic In process Dressing (ELID). It was first demonstrated by Mutara et al. and further developed by Ohmori and Nakagawa for machining of ceramic materials with metal bonded diamond grinding wheel [26-28]. Figure 5 shows the electro chemical action during grinding process. The ELID process enables continuous dressing of metal bonded wheel and maintains sharpness of the abrasives.

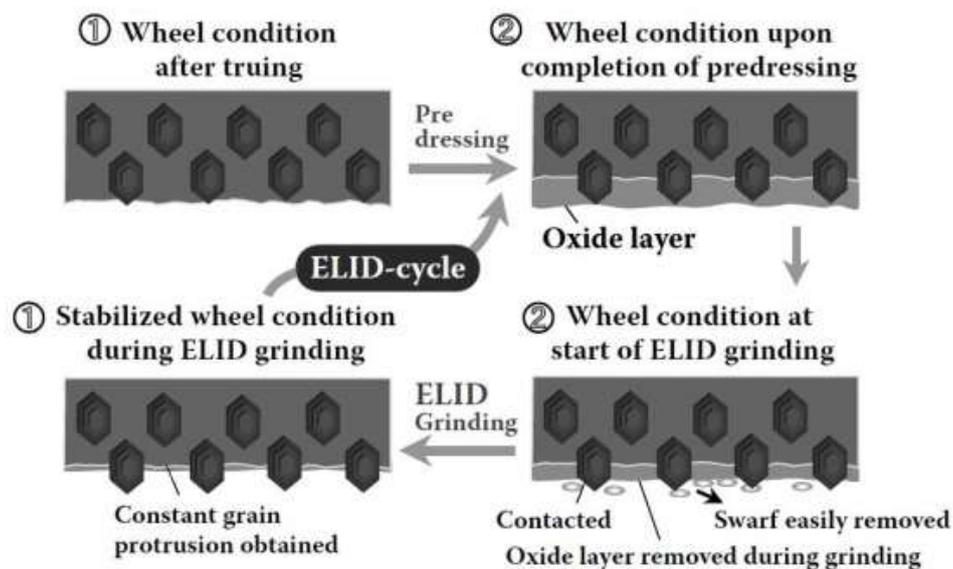


Figure 5 Mechanism of bond material removal is due electro chemical action during grinding process [25]

Super abrasive wheels bonded with cast iron, cast iron fibers, and bronze materials have been established for machining of silicon wafers, aluminium-silicon-carbide metal matrix composites, ceramics balls, sapphire and BK7 materials, using ELID process [29-32]. Further, ELID has been extended to conductive resin bonded super abrasive grinding wheels for fine finishing process [33-34].

3.1.2. Active Dissolution Method

The active dissolution method also requires an arrangement for electrolysis to take place at the metal bonded wheel periphery. The electrolysis process causes the removal of metallic ions from the wheel surface, thereby eroding a layer of the metal bond and giving rise to grain protrusion. In this process, the electrode gap is continuously monitored to assess the wheel sharpness by a suitable technique. The electrolyte usually contains aggressive ions which

destabilizes the formation of the films noted in passive dissolution method. This method is popular under the name, Electro-chemical in-process Controlled Dressing (ECCD) [35-36]. Golabczak and Koziarskj used alternative current supply and found to be effective with change of polarity in a cycle compared to direct current. [37]. On the other hand, dual electrodes with alternative current for dressing of metal bonded wheels were explored by the investigators. In this, flow of alternative current between first and second electrodes and vice versa enables removal of bond material effectively from the grinding wheel [38].

3.2. Electro-physical Method

Self-dressing by electro-physical method involves phase change of solid bond materials through a Melting-Evaporation or a Melting-Flushing process with high energy heat sources such as laser, electric spark, arc, etc. The thermal energy is generated through conversion of electrical or optical energy. The controlled removal of bonding material ensures the self-dressing of bonded abrasive tools throughout the process.

3.2.1. Laser Ablation

In laser induced thermal processing methods, photothermal and photochemical mechanisms can be active depending upon characteristics of laser, its excitation time and the type of wheel bond. Evaporation and sublimation comes under photo-thermal mechanisms which happen at low fluence whereas photochemical ablation mechanism occurs at higher fluence with shorter excitation time. All these mechanisms are being exploited in dressing of fixed abrasive tools [39]. Figure 6 shows laser dressing process.

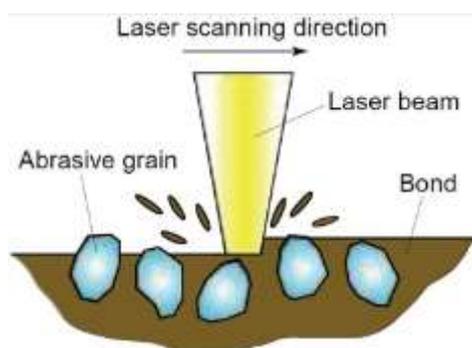


Figure 6 Shows the principle of laser dressing [40].

Table 1 Laser sources and parameters in dressing of grinding wheels.

Type of Laser	Laser Parameters	Type of Wheel used
Continuous Wave Laser	Nd:YAG laser, 2.5 kW	Vitrified alumina wheel [43-45]
Pulsed laser Pulse width $\geq 1\mu\text{s}$	Nd: YAG laser, Pulse width: 0.6 ms, 10 ms, 0.46 ms, and 5 ms	Resin bonded CBN [46], vitrified CBN [47], vitrified alumina [41], Resin and Bronze-bonded diamond grinding wheels [48].
Short Pulsed laser. Pulse width ($1\mu\text{s} > x \geq 1\text{ns}$)	Fiber laser: 210 ns, acousto optic Q-switched pulsed Nd: YAG laser: 150 ns, 170ns and 125 ns	Bronze-bonded diamond [49], resin bonded CBN and Diamond [50], bronze-bonded diamond [51], hybrid (metal and vitrified) bond CBN grinding wheels [52].
Ultra short pulsed laser pulse width $\leq 1\text{ ns}$	Picosecond Yb:YAG laser	Resin bonded CBN [53], metal-bonded CBN and diamond [54], and nickel bonded electroplated diamond grinding wheels[55]

Initially, Ramesh Babu et al. explored the possibility of laser dressing of conventional alumina and silicon carbide vitrified bonded wheel with Nd:YAG pulsed laser [41]. This approach was also applied to resin bonded alumina wheels, metal and hybrid bonded super abrasive grinding wheels. Based on the type of abrasives and bonding medium, continuous wave laser, pulsed laser, short pulsed laser or ultra-short pulsed laser sources are being utilized to dress the grinding wheel by controlled removal of bond materials [42]. The laser irradiated layer of wheel bond is efficiently removed when pulsed laser is used, compared to continuous wave laser. It also imparts low thermal stresses on the wheel and so it is preferred for truing and dressing operations. However, considering the huge investments needed to integrate the laser system with the grinding machine, laser dressing could not be justified for all kinds of wheel dressing applications. Table 1 represents different laser sources for dressing of conventional and super abrasive wheels.

3.2.2. *Electro Erosion*

In this method, the wheel dressing is accomplished by controlled removal of bond material by electrical erosion as a result of electric discharge between conductive tool and electrode in a dielectric medium. During discharge, the electrode interface is subject to ionization and very high temperature, leading to melting of the metal bond of the wheel. Thus, a selective removal process takes place which can be controlled to produce the required wheel sharpening and truing action [56-57]. Electro discharge dressing (EDD) method was initially utilized for conditioning of grinding wheels by Suzukhi et al [58]. It has been applied for super abrasive wheels [59-61] Nowicki et al have developed electro-discharge mechanical dressing (EDMD) method for metal bonded diamond wheel, in which brush electrodes were additionally used to remove thin layer of the bond material that has melt [62]. By coating a layer of electrically conductive material over the surface of a non-conductive wheel, the EDD technique was applied to dress the resinoid or vitrified bonded CBN wheels [63]. On the other hand, electro contact dressing has been developed, wherein a copper or graphite electrode is fed towards the grinding wheel which is connected to DC power. An electric discharge takes place between the electrode swarf and the wheel bond, causing local erosion and removal of the wheel bond [64-66].

4. CONCLUSIONS

The mechanisms of wheel sharpening that occurs in conventional and super wheels have been studied. Several in-process dressing methods are in use to keep the wheel sharp throughout the grinding operation. Though, self-activated, self-dressing mechanisms attracts great research interest as a sustainable process, external assisted dressing mechanisms are emerging in the field of wheel dressing to meet the process requirements. Therefore, a comprehensive understanding of conventional and unconventional dressing methods is necessary for economic and efficient generation of high quality surfaces using fine abrasives.

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