Chapter 10

Theories on Rock Cutting, Grinding and Polishing Mechanisms

Irfan Celal Engin

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/56046

1. Introduction

Tribological research studies including cutting, abrading and polishing mechanisms have firstly started with metals, metal cutting theories and formulas have been developed and then applications on rock material have started. In this part of the book, natural stone cutting, abrasion and polishing mechanisms are compiled and presented as a summary.

Processes of cutting, grinding and polishing natural stones are made as a result of grinding-abrading mechanism developed on the use of different abrasive grains (mostly diamond and SiC). Wear intensity is named as cutting, abrading or polishing according to the speed, chip size and situation of obtained surfaces.

No matter which cutting machine is used, generally cutting process of natural stones are done with the use of segments that are obtained through sintering of diamond grains and metal powders. Industrial diamond grains in these segments rubbed against the material to be cut with a certain force and material is removed, and as a result, the material is cut along this surface as the material is removed as much as segment width.

In the stage of abrading and polishing of natural stones, products called grinding stone containing SiC grains are generally used. Intenseness of material removal from natural stone surfaces can be arranged by changing grain size of this abrasive and magnitude of pressure intensity. When relatively coarser grains and higher pressures are chosen, coarse abrading process is obtained while slight abrading and polishing is obtained when slighter grains and lower pressures are chosen.

2. The basic wear mechanisms emerging all types of materials

Wear is described in the literature as the loss of material as a result of the change in the shape of friction surfaces. Many researchers have stated that there are 4 main wear mechanisms causing the loss of material. These are adhesive wear, abrasive wear, and corrosive wear and wear resulting from surface fatigue (Archard, 1953; Moore, 1975; Suh and Saka, 1978; Williams, 1994; Summer, 1994). Similarly, many researchers have classified wear as heavy wear and light wear according to the wear magnitude.

A basic equation about wear is developed by Archard (1953). According to Archard (1953), wear on friction surfaces (w), is directly proportional to applied load (W) while inversely proportional to the strength of material (H).

$$w = K \, x \, \frac{W}{H} \tag{1}$$

K which is non-dimensional in here is expressed as wear coefficient. This coefficient is changed into k=K/H including strength; this is the dimensional wear coefficient which is more widely accepted in engineering. This coefficient represents the volumetric wear (mm^3) resulting from the shift in unit distance (m) under unit load (N).

When two materials are rubbed against each other, stresses on touch point can easily reach yield point. With the shearing effect of lateral force, material transfers from the surface of soft material to the surface of hard piece and sticks on. Wear developed this way is called adhesive wear. A simple demonstration of this is presented by Archard (1953) (Figure 1):

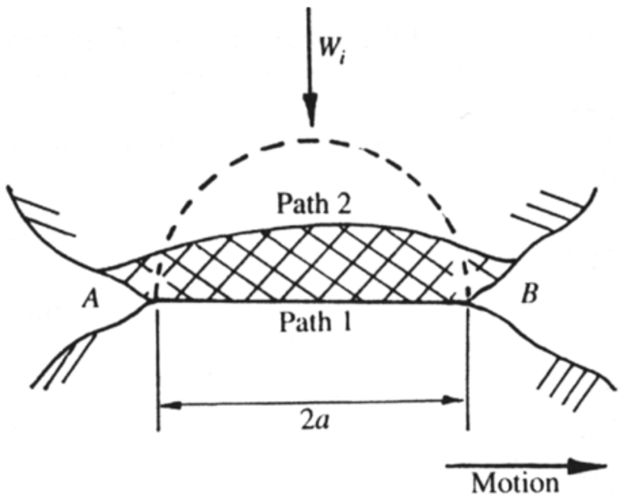

Figure 1. Material wear caused by the adhesion on friction surfaces (Archard, 1953)

Here, the diameter of contact point is shown as 2a, applied load is shown as W. It is thought that moving will be along the way shown as Path 2. For convenience, the part that will be abraded is assumed to be in the shape of a radius sphere and wear amount as a result of 2a amount of shifting. Wear per unit shifting distance is calculated as $1/3\pi a^2$, by dividing $2/3\pi a^3$ to 2a. As change in the shape is permanent, Wi load is presented as Wi = H a^2 material strength and type. At the end, total wear is shown as;

$$w = \frac{\pi}{3} x \sum a^2 = \frac{1}{3\pi} x \sum \frac{\pi Wi}{H} = \frac{W}{3H} \tag{2}$$

This ($W = \sum Wi$) means the total load applied by both surfaces.

If a solid material or a solid particle removes piece by scratching or rubbing, this is defined as abrasive wear. Abrasive wear comes through as long rents on surfaces in parallel with the friction direction. A simple model based on the assumption that there is not any change on grain, it only pass through soft material by rubbing it inside is presented in Figure 2. Here, normal load is shown with W, depth on the surface caused by abrasive grain is shown with h, and cone angle is shown with υ.

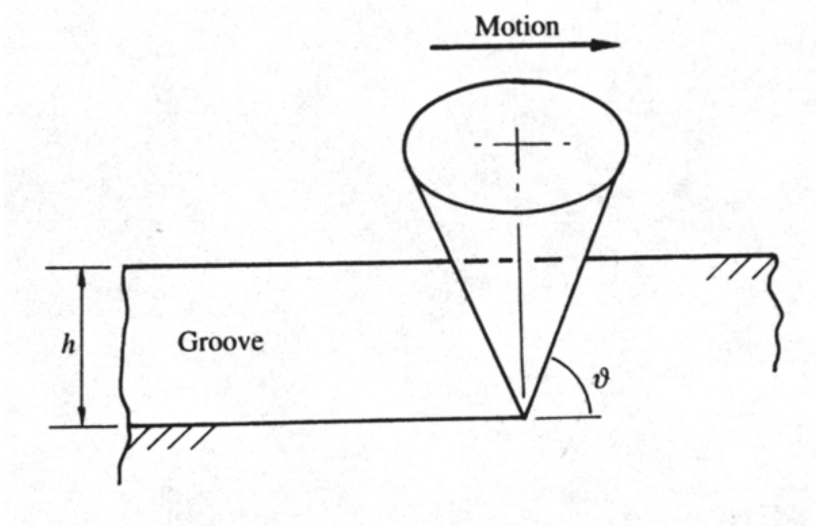

Figure 2. Movement of a cone shaped abrasive on a soft surface (Williams, 1994)

Here normal load is given as;

$$W = h^2 \text{ x } \cot\vartheta \tag{3}$$

When depth of surface caused by the grain is given as material strength, load is defined as;

$$W = \frac{\pi}{2} \text{ x } \left(h\cot\vartheta\right)^2 \text{ x } H \tag{4}$$

As a result, wear is given as this equation;

$$w = \frac{2\tan\vartheta}{\pi} \text{ x } \frac{W}{H} \tag{5}$$

If abrasive grain is prismatic instead of cone, wear becomes more complex. The structure of chip created as a result of wear is based on two angles to a great extends besides affecting forces. The first is contact angle which is the surface of abrasive grain on the side of moving angle in the direction of sliding. The second is the dihedral angle (2) which is the angle between the sides of pyramid in the direction of movement (Figure 3).

Contact angle is very important for wear, because while abrasive grain cuts chips over critical contact angles (ψ_c), it only breaks through or rubs in lower angles.

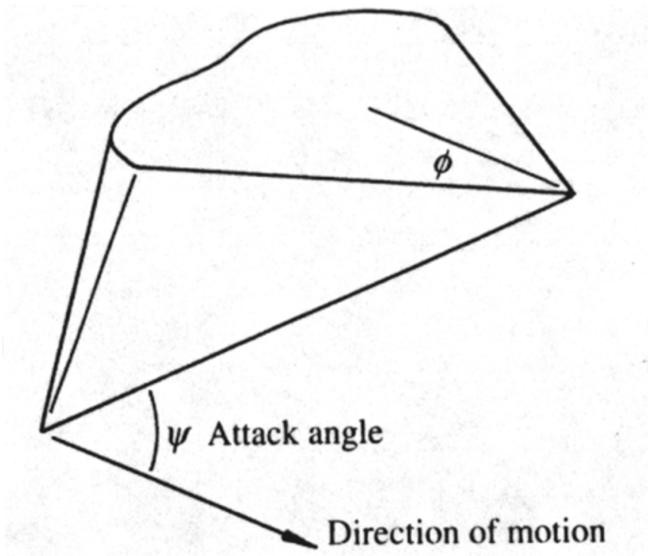

Figure 3. Geometry of prismatic abrasive grain represented with two angle ((ψ, 2ϕ) (Williams, 1994)

Dihedral angle also significantly affects the shape of chip. In very small 2 angles, abrasive grain breaks through the surface like a knife. When 2ϕ=180, it means there is a smooth surface vertical to the motion direction and this is a limiting value.

Relation between contact angle and dihedral angle developed by Kato et al. (1986) is given in Figure 4.

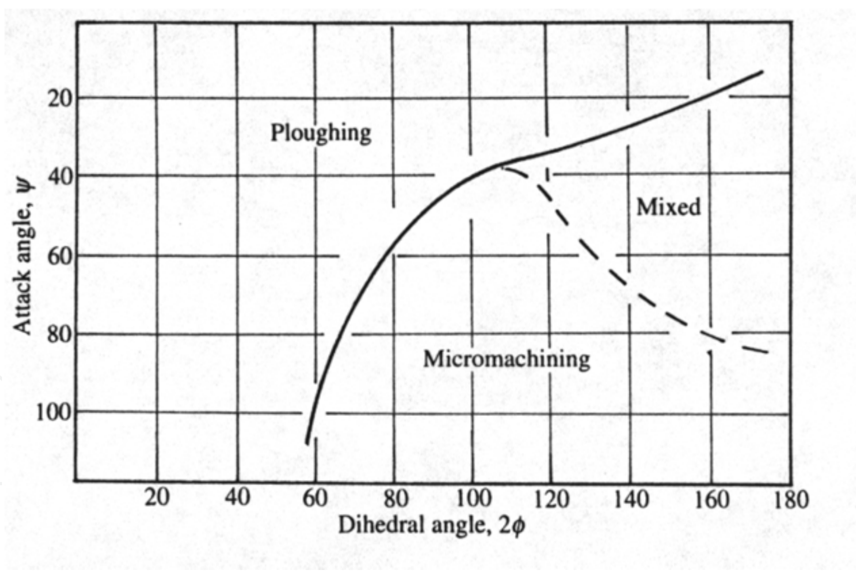

Figure 4. Relation between contact angle and dihedral angle with wear situations resulting from abrasive wear (Kato et al., 1986)

Corrosive wear occurs on surfaces that rubbed against each other with small vibrations and as a result of this, few ten micron grains are removed. Generally when irony surfaces are rubbed against one another, a reddish brown fragment is produced. This detritus is composed of solid iron oxide grains and behaves like polishing powder and make contacting surfaces smooth and shiny. This leads to the creation of a film in the shape of a protector layer on these surfaces. If wear occurs because of mechanic factors and environment involves similar atmospheric conditions, this film layer will remove and a new layer will occur as a result of re-oxidation. Grains that are formed during removal of this layer can cause abrasive wear because of their solidity. Adhesive wear can also occur as a result of friction if a part of contacting surfaces is oxidized while another part is completely non-oxidized. As a result, if this corrosion layer is continuously removing because of wear, this will have a positive effect on wear process which is named corrosive wear (Summer, 1994). Wear as a result of surface fatigue occurs generally on metal materials rolling on one another similar to the bearings. Material in contact point tightens as a result of permanent change in the shape and material embrittlement occurs. This material cracks as a result of repetitive power; they spread on the surface in time and cause breakage of material in small pieces.

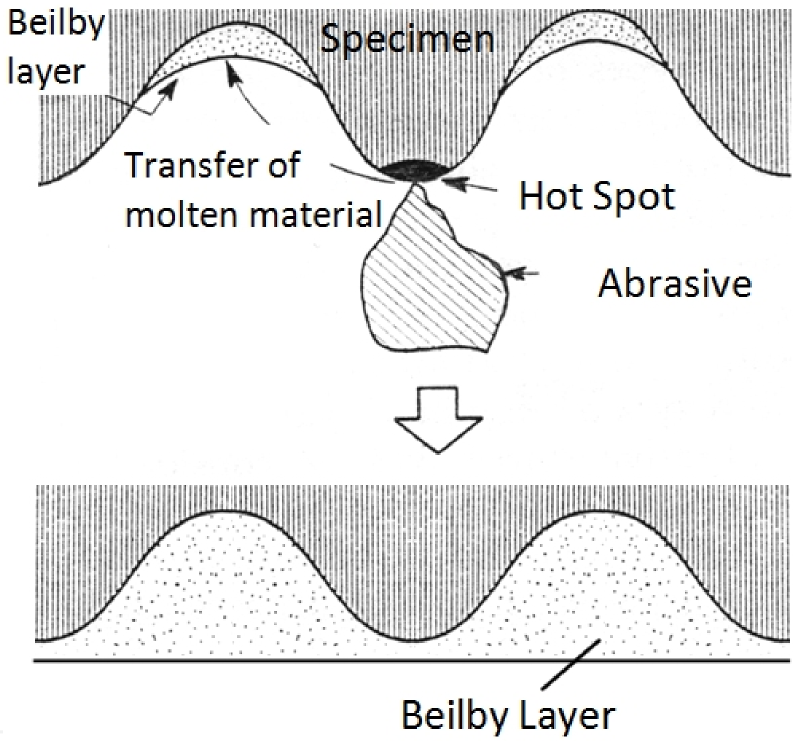

Figure 5. Beilby polishing mechanism developed by Bowden and Hughes (1937)

In the wear process resulting from surface fatigue, bigger grains remove from the surface when compared to adhesive or abrasive wear. Typical cavitations and scouring occur on these types of surfaces.

Wear mechanisms that are stated until here explain unwanted material loss on surfaces.

Abrading on the other hand, is the deliberate process of removing material from surfaces with various applications and in accordance with the purpose.

Polishing is a process of abrading and it is defined as the process of removing unevenness and visible scratches by using abrasive material (Coes, 1971). So, polished surface reflects light smoothly and in a linear way (Coes, 1971; Samuels, 1971).

According to Beilby (1921), polishing results from a smearing a material on a surface which fills the gaps on surface. Beilby (1921) stated that this material has a structure that is completely similar to amorphous and it looses crystal structure. He didn't suggest a mechanism about smearing material on these surfaces. But later on, a mechanism was developed by Bowden and Hughes (1937). These researchers determined that very high temperatures were reached in the contact points of abrasive grains, as a result of rubbing solids against each other which caused them think that heat is significant in the process of polishing (Samuels, 1971).

Unevenness on the original surface heat locally (until melting point) which is caused by friction transfers to the gaps (Figure 5). This material is transferred as a result of rapid cooling, it has an amorphous structure and constitutes Beilby layer.

On the other hand, Samuels (1971) didn't accept the existence of Beilby layer and tried to prove that Beilby layer doesn't occur with many proofs. According to Samuels (1971), there exists continuous material loss during polishing on surfaces that are physically polished. In addition, when polished surfaces are analyzed with microscope, scratches can be seen. This situation is completely opposite the existence of Beilby layer. Because Beilby stated that material fill the gaps during polishing. There shouldn't be a distinct material loss.

When physically polished surfaces are treated with acid, scratches on the surface appear. According to Samuels (1971), this situation can be explained with the deformed layer (as can be seen in Figure 6) rather than Beilby layer.

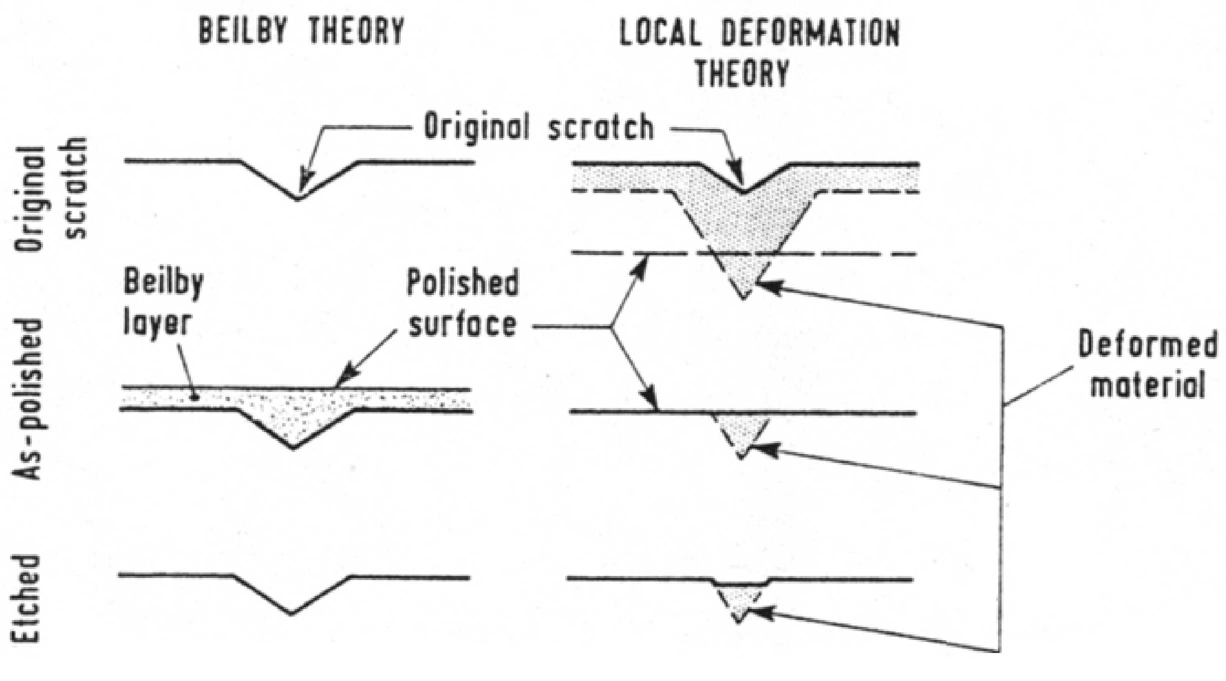

Figure 6. Comparison of Beilby and local deformation theory (Samuels, 1971)

According to Samuels (1971), one needs to explain three acceptations in order to explain physical polishing mechanism. The first is that, surfaces always have thin scratches or joint sets. The second point is that material is removed from the surface during polishing process with a constant speed. Thirdly, a layer that has permanently deformed is created. This layer is highly similar to transformed layer that is created during abrading. When grinded and polished surfaces are examined, the significant similarity between them will be seen. Scale is the only difference. Most of the researches and studies on abrading and polishing process focus on metallic materials. Studies on brittle and fragile surfaces like rock surface are very limited.

In this section, abrading and polishing processes that are based upon mechanic materials are taken into consideration. When abrading and polishing mechanisms are analyzed in these terms, it is seen that there is not a basic difference between them. By changing the abrasive material type and/or application style of gain size, abrading process can be transformed to polishing.

Explanation of abrading and polishing mechanism is possible only by revealing the type and aim of the applied process. So, mechanisms that occur at each application will be different from one another.

These applications can be lined as;

- Wear mechanism formed during the use of circular saw, grinding mills, and grinding cutting stones.
- Wear mechanism during cutting process with diamond blade saws.
- Wear mechanism during cutting process with diamond bead system
- Wear mechanism during surface polishing applications
- Wear mechanism during the use of sandpaper

Abrading processes mentioned above have significant differences in terms of basic mechanism. This is why, each one of them will be analyzed and what kind of abrading and/or polishing mechanism develops will be put forward.

3. Wear mechanism that is formed during the use of circular saw, grinding mills, grinding stones

Circular saws is the cutting tool that is used the most in cutting and sizing of natural stones that are segments containing diamonds' welded around circular metal body. Grinding mills are used for process such as cutting, graving, shaping… etc. In the abrading operation mentioned until here, the process of wear results from simple geometrical situations with a linear movement between abrasive grain and material. When grinding mills are analyzed, if abrading operation occurs on the edge of grinding mill, the situation is simple. But if abrading is on the disc, the situation is complex. In the literature, abrading mechanism that occurs here is mentioned with the word grinding. The wear that occurs here is defined as a micro-scaled grinding.

Salmon (1992) tried to make a mathematical modeling for the abrading operation on the surface of grinding mill.

Situation of grinding mill during the operation is geometrically shown in Figure 7.

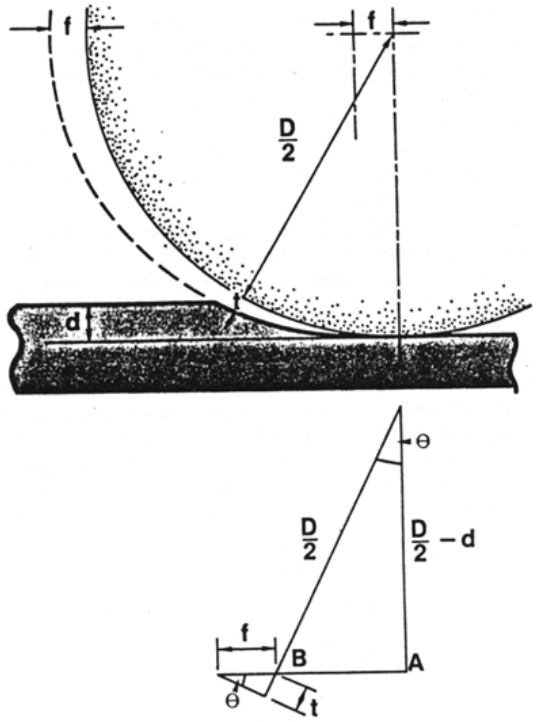

Figure 7. Geometric presentation of wear produced during grinding mill application (Salmon, 1992)

Symbols that are shown here and that will be used hereafter is shown below:

D: Diameter of grinding mill (mm)
V_s: Peripheral speed of grinding mill (m/s)
w: Angular speed of grinding mill (rad/s)
V_w: Feedrate of material
K: Number of abrasive grains along a peripheral line
C: Number of active abrasive grains per unit
t: Cutting depth of abrasive grains (mm)
l: Length of cutting trajectory
d: Cutting depth of grinding mill (mm)
b′: Theoretical width of each grain (mm)
b: Cutting width of abrasive grain (mm)

Salmon (1992) made these approaches;

Length of cutting trajectory can be determined as below:

$$l^2 = D^2 / 4 - (D / 2 - d)^2 + d^2$$

$$= D.d$$

$$l = (D.d)^{0.5} \tag{6}$$

According to the geometrical structure in the figure;

$$AB = \left((D/2)^2 - (D/2 - d)^2\right)^{0.5}$$

Calculated as such:

$$AB = \left(d(D-d)\right)^{0.5}$$

Cutting arc is accepted to be a straight line and the mill -along a peripheral line- that contain K amount of abrasive grain, proceeds as much as f with 1/K turn. Cutting depth of abrasive grains is calculated as:

$$t = f(Sin\theta) = f(AB)/(D/2) = 2f\left(d(D-d)\right)^{0.5}/D$$

As d, is at a small value according to D,

$$t = 2f(d/D)^{0.5} \quad f = V_w/(Kw)$$

$$t = (2V_w/Kw)(d/D)^{0.5} \text{ can be written} \tag{7}$$

Number of abrasive grains along a peripheral line ise determined with the equation below.

$$K = \pi.D.b'.C$$

If abrasive grain is represented as such (Figure 8);

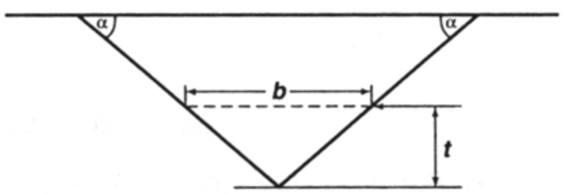

Figure 8. Frontal view of the presented grain (Salmon, 1992)

t/2 is used as average grain cutting depth. So, the ratio of grain width to cutting depth will be:

$$r = 2b'/t$$

$K = \pi.D.b'.C$ equation turns to $K = \pi.DrtC/2$. If this is put in Equation 7;

$t = (d/D)^{0.5}(4V_w/\pi DV_sCrt)$ is reached. $V_s = \pi.D.\omega$ so;

$$t^2 = (4V_w d / V_s Crl) \tag{8}$$

Cutting geometry when abrasive grain is considered, cutting geometry is presented in Figure 9.

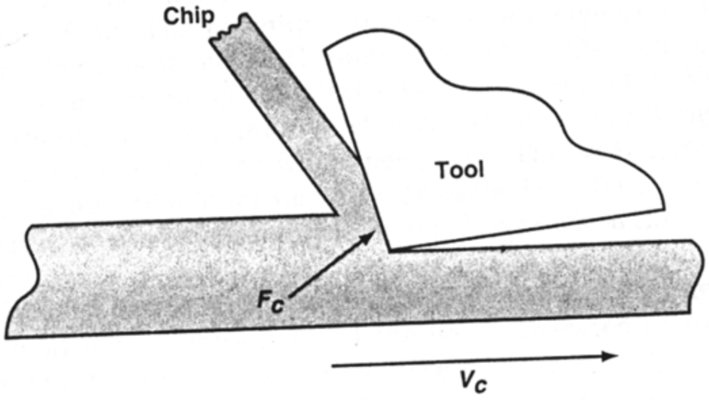

Figure 9. Cutting geometry of a abrasive grain. (Salmon, 1992)

Here;

b: Cutting width (mm)
t: Thickness of chip that is not deformed (mm)
u: Specific energy (Jmm^{-3});
For cutting operation at one point;

$$u = F_c V_c / b + V_c$$

$$\text{Cutting Force} = F_c - ubt$$

Cutting force in abrading is used as tangential force. So, equation is arranges as $u' = F + V_s / V_u bd$.

Cutting Force = $F_c u'bdV_u/V_s$

Work done in unit of time: u'Vubd

Number of abrasive grain working at unit of time: V_sCb

Work done by one single grain = u'Vud / V_sC

Average force affecting one single grain F″ is calculated by dividing the work done by one grain into the length of cutting arc.

$$F'' = u'Vud \ / \ V_s Cl \qquad (9)$$

From Equation 8:

$$t^2 = 4\ Vud /\ V_s Crl \qquad => \qquad l = 4\ Vud /\ V_s Cr\ t^2$$

When l is put into the place in Equation 9,

$$F'' = u't^2 r \ / \ 4 \qquad (10)$$

is obtained.

According to Salmon (1992), it is possible to solve wear problems in grinding mill applications and present alternative solutions.

In terms of energy need, in order to remove material from the surface, the most efficient phase is this cutting phase. Minimum specific energy is used in this way. Here, specific energy is the energy that is needed for removing unit material form the surface and unit is joule/mm^3 or Btu/in^3.

According to Salmon (1992), energy used during abrading in which chip is shaped can occur in these ways:

- Heating on working material,
- Heat occurs at grinding unit,
- Heat that occurs at chips,
- Kinetic energy at chips,
- Radiation diffused around,
- Energy spent on producing new surface,
- Residual stress in the surface and chip's lattice structure.

Another approach for grinding mills is developed by Chen and Rowe (1996). According to Chen and Rowe (1996), when a abrasive grain on the surface of a moving chip is thought; firstly, abrasive grain combines on the material with a narrow curve. In this way, more material is removed. Secondly, productive contact point of the surface of abrading changes as long as it moves on this contact arc.

So, as can be seen in Figure 10, while abrasive grain made "ploughing" at the beginning of this arc, the rest of is can make cutting.

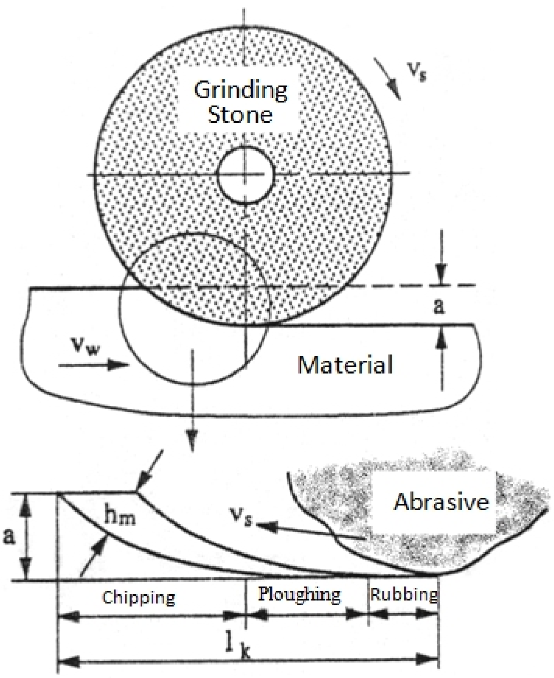

Figure 10. Phases of chip formation on the edge to grinding mill (Chen and Rowe, 1996)

In Figure 10, production of chip by grain on grinding mill during the movement of chip is seen. Cutting arc length of grain is shown with l_k, thickest chip thickness that hasn't changed shape is shown with h_m, tangential turning speed of mill is represented with V_s, progress speed of processed material is represented with V_w, cutting depth is represented with a.

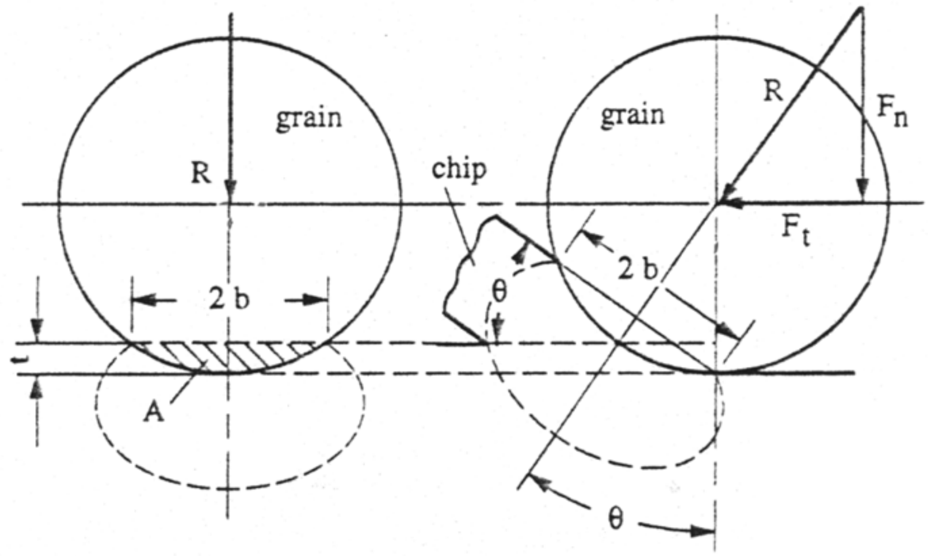

Figure 11. Behavior of circular grain in abrading (Chen and Rowe, 1996)

Movement of a circular grain on the edge of mill during abrading is shown in Figure 11. Cutting depth of grain in here is represented with t, amount of pressure with R, its horizontal component with F_t, vertical component with F_n, cross sectional area of chip that hasn't gone under any change with A, diameter of circular area which is the section of this on the surface with b, angle between power of pressure and vertical with θ. Pressure force affecting grain is represented with

$$R = \pi b \ H(C^{'} / 3) \tag{11}$$

Here C is the strain factor defined as the rate of average pressure affecting contact area to normal stress. Necessary specific energy is defined as;

$$e_c = F_t / A \tag{12}$$

When $A = \frac{4}{3}bt$, if necessary specific energy is used for cutting,

$$e_{cc} = \frac{3RSin\theta}{4bt} \tag{13}$$

When is put in the equation, specific energy is calculated as below:

$$e_{cc} = \frac{3\pi}{4}\frac{b}{t}H\left(\frac{C'}{3}\right)Sin\theta \tag{14}$$

When friction force is taken as μRCos, specific energy in friction is obtained as;

$$e_f = \frac{3\pi}{4}\mu\frac{b}{t}H\left(\frac{C'}{3}\right)Cos\theta \tag{15}$$

total specific energy for grain is formulized as below.

$$e_g = \frac{3\pi}{4}\frac{b}{t}H\left(\frac{C'}{3}\right)\left(Sin\theta + \mu Cos\theta\right) \tag{16}$$

In parallel with common use of grinding mills in the industry, there are many studies in the literature about grinding mills.

4. Wear mechanism formed in the process of cutting with diamond frame saw

Generally rock cutting mechanism is explained by the formation of indentation with plastic deformation and breaking mechanism of rock. When cutting depth of diamond is deep enough to produce visible cracks on a rock, breakages occur and chips are formed as a result of this. As can be seen schematically in Figure 12, there is a plastic deformation under the channel that is produced by the tangential movement of abrasive grain along the surface and there are two main crack systems named radial and lateral that are produced from this zone. Radial cracks are formed with wedge wear type when high normal force is used and when this force is removed, these cracks can continue to spread because of permanent tensile stress at the edge of crack. Lateral cracks start to be formed when he force is removed and can continue to spread with the effect of permanent tension (Konstanty, 2002).

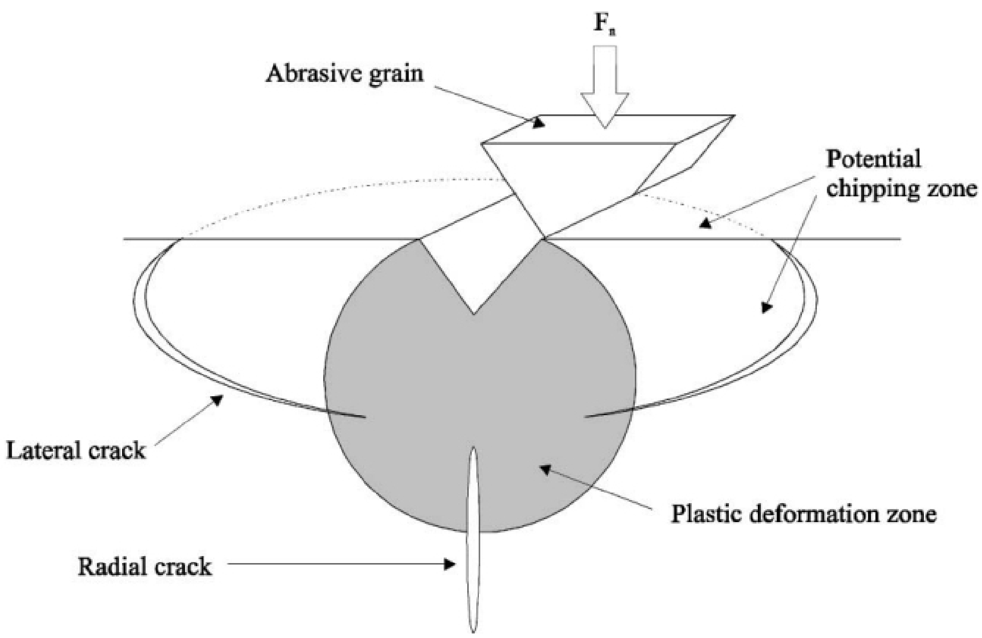

Figure 12. Schematic view of plastic deformation zone formed during cutting (Konstanty, 2002)

In the cutting process with diamond segmented blades are moved with reciprocating motion at a sinusoidal speed that is about 2 m/s. Konstanty (2002) made some researches on the cutting mechanism with diamond blade saw and defined the cutting zone during this cutting. Schematic view of cutting zone determined by Konstanty (2002) is shown in figure 13. Here, in order to make the definition, it is accepted that diamond grains in diamond zones are placed with the same protrusion height and cutting zone is the same all along the segment. But diamond grains on diamond segments have different protrusion heights**.** This complicates the process of defining cutting process. As can be seen in the cutting zone in figure 3.20, a pressure is produced on matrix as rock fragments accumulated in the front and behind the diamond grains can not be removed. Magnitude of pressure resulting from the wedging of rock fragments cause wear in the contact zone that is the weakest point between diamond and matrix.

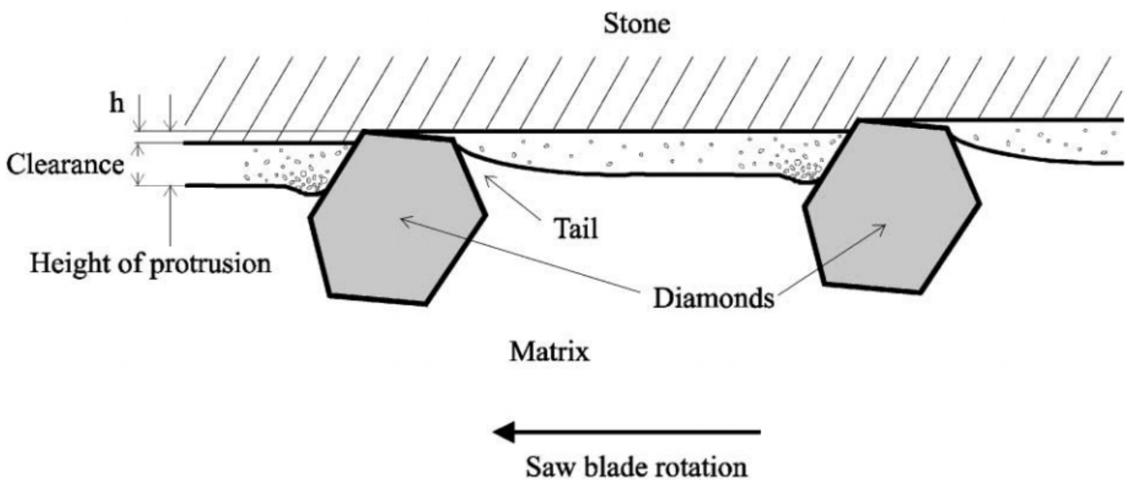

Figure 13. Schematic demonstration of cutting zone in the frame sawing system (Konstanty, 2002)

In the process of cutting with diamond blade saw, cutting of diamond segments is similar with cutting of many diamond grains. Cutting principal of diamond grain in segments are shown in Figure 14.

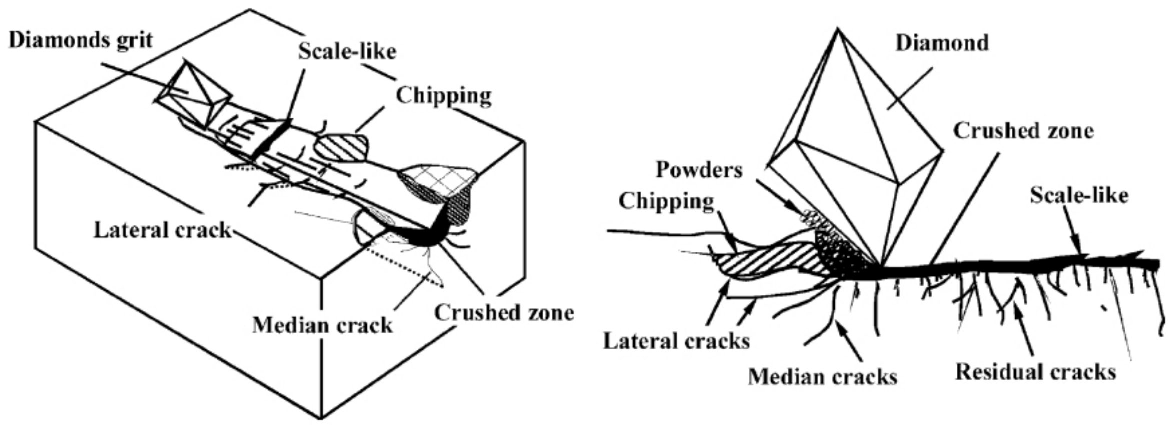

Figure 14. Cutting mechanism of marble with diamond grain (Wang and Clausen, 2002)

As can be seen in Figure 14, the main deformation of natural stone in low cutting depth is explained as plastic deformation. In parallel with the increase in cutting depth, while lateral cracks increase, plastic deformation of natural stone decreases and as a result, chip is formed. Some small lateral cracks on the surface can have a flaky structure on the base of cutting channel like a shell. Lateral cracks on different directions leave the semicircular channel behind the diamond the cuts on the surface. Plastic deformation zone stays on the base of cutting channel. Divergence on the cutting zone resulting from the increase of shearing cracks on the surface along the breaking zone seems like a continuous chip formation (Wang and Clausen, 2002).

Cutting with diamond blade saw is the continuous cutting movement of many segments on the surface of rock. Cutting with diamond segment can be defined as the cutting of a diamond cutter that cuts from many points in different cutting depths. As diamonds make chips and cuts, cracks are formed and they join and as a result of this, natural stone is broken. This situation is given in Figure 15 as stated by Wang and Clausen (2002).

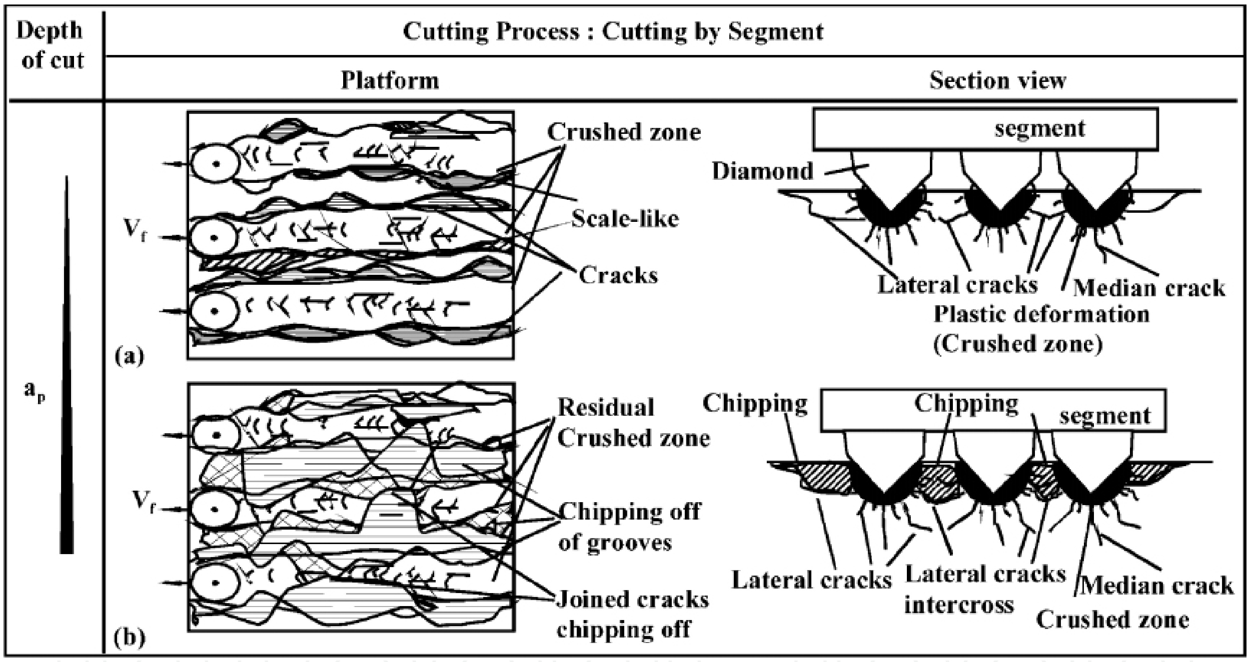

Figure 15. Cutting process of marble with diamond segments (Wang and Clausen, 2002)

Natural stone cutting mechanism with diamond blade saw system is explained as plastic deformation (breaking zone) and brittle breaking of rock. Formation of chip can be used in the explanation of cutting with frame saw system as s baseline. Plastic deformation and breaking of rock is affected from cutting conditions such as cutting depth, cooling operation, shape of cutter and aspects of rock (Konstanty, 2002; Wang and Clausen, 2002).

5. Wear mechanism formed during cutting with diamond wire system

The principle behind diamond wire cutting involves pulling a spinning, continuous loop of wire mounted with diamond bonded steel beads through the stone to provide the cutting action (Figure 16). Through the combination of the spinning wire and the constant pulling force on the wire, a path is cut through the stone. In marble quarrying through diamond wire cutting, the initial step for making a vertical cut is to drill two holes, one vertical and one horizontal, which intersect at a 90° angle. The diamond wire is then threaded through these holes, mounted around the drive wheel, and the two ends are clamped together to form a continuous loop. The drive wheel may be set at any angle, from vertical to horizontal, required to facilitate cutting.

The diamond wire is comprised of a steel cable on which small beads bonded with diamond abrasive are mounted at regular intervals with spacing material placed between the beads. The beads provide the actual cutting action in this operation. They are bonded with diamond by one of the two methods: electroplating or impregnated metal powder bonding.

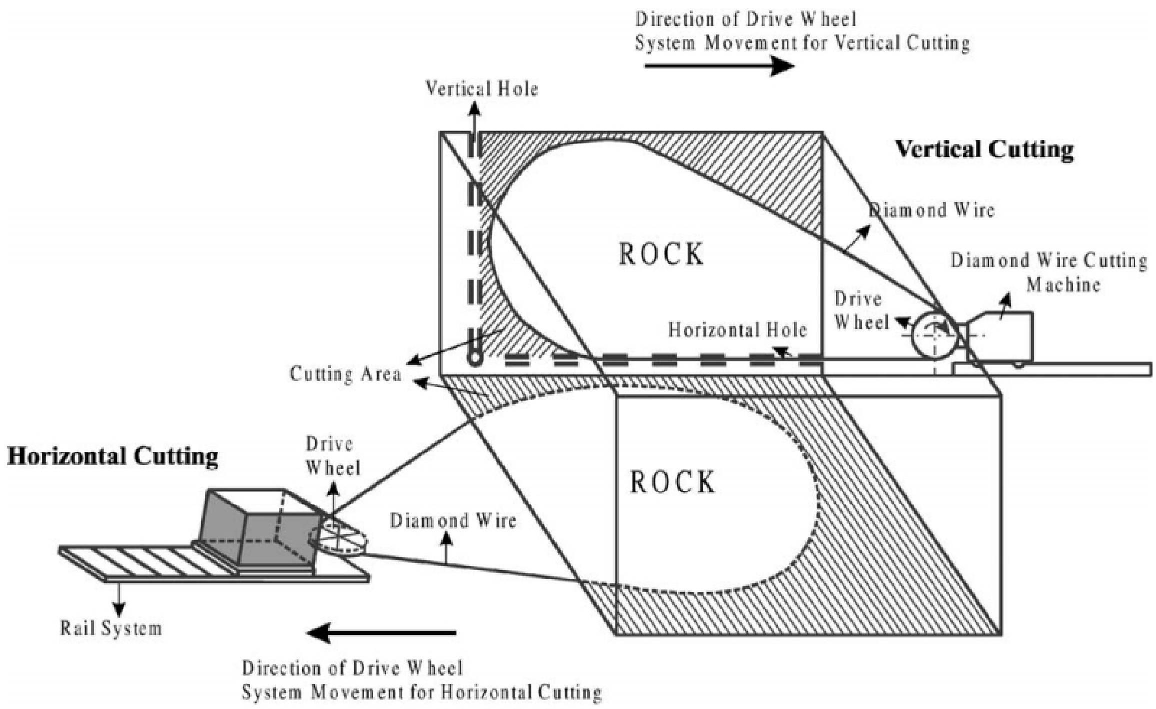

Figure 16. Situation of the diamond wire during the cutting operation (Ozcelik et al., 2002)

In the process of cutting with diamond wire system (Figure 17), diamond grains, sintered with metal powder as bead form, contact material surface similar with the circular saw and make grinding, cutting or abrading processes according to contact angle.

During cutting natural stone with diamond wire, contact angle between diamond grains and rock surface vary according to the path of steel rope (on which diamond beads are lined) in the rock rather than the diamond grains on bead.

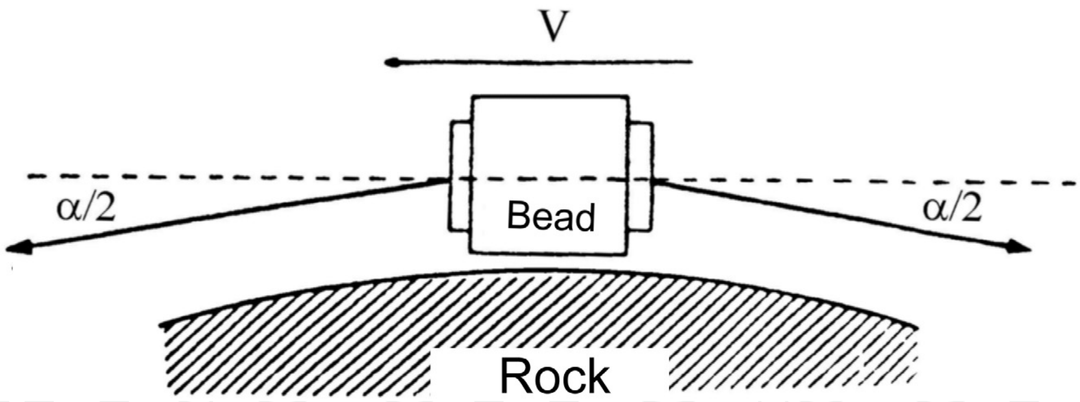

Figure 17. Schematic presentation of cutting the natural stone with diamond bead (Bortolussi et al., 1994)

6. Wear mechanism formed during surface polishing applications

This mechanism includes abrading and polishing mechanisms on grinding heads that are used for leveling and polishing of surfaces of different materials.

Although some of grinding mills are used in the literature, there are some significant differences between the grinding mechanisms of grinding mills. Abrading that is made with the help of abrasive grains on the surface of grinding heads is in fact quite similar with the abrading on sandpaper. Abrasive grains on the abrading product makes cutting, rubbing or ploughing as of their position. According to the application of abrading operation, complication of the mechanism is somewhere in between the mechanisms that are produced in sandpaper and grinding mill applications.

If grinding heads is turning around vertical axis on material surface, grains on it will make cutting, breaking through or friction during abrading. If there is the linear movement besides turning, the situation will be more complicated. Abrasive grain will be able to make these three moves during operation in different times.

In figure 18, the model that is developed by Lawn and Swain (1975) about crack movement on material surface and material removal. At the first contact point between grinding and surface, because of the applied loads high stress occurs. If the tip of the abrasive grain is perfectly sharp (namely, if radius of curvature is 0) stresses at this point will be infinite. These dense stresses relax with permanent changes in the shape and changes in density.

When applied loads reach a critical value, the middle crack shown with M start to increase because of tensile stress occur on vertical plane. In parallel with the decrease of load, middle fracture filling and when it reduced more, lateral cracks shown with L occur. These cracks are formed as there are residue elastic stresses after relaxation in contact points. Crack reaches surface with the removal of complete load and it cause wear with the breaking of material from surface.

According to Chandrasekar and Farris (1997), a few mechanisms are dominant in removing material from brittle surfaces. These are brittle break that is formed according to crack systems that is parallel and vertical to the surface and ductile cutting in the shape of chip similar to slim ribbon. The process that will occur depends on the load on abrasive grain, location and velocity of slip. Abrading process cause destruction in places close to the surface in the shape of small scaled crack, residual stress and permanent change in shape.

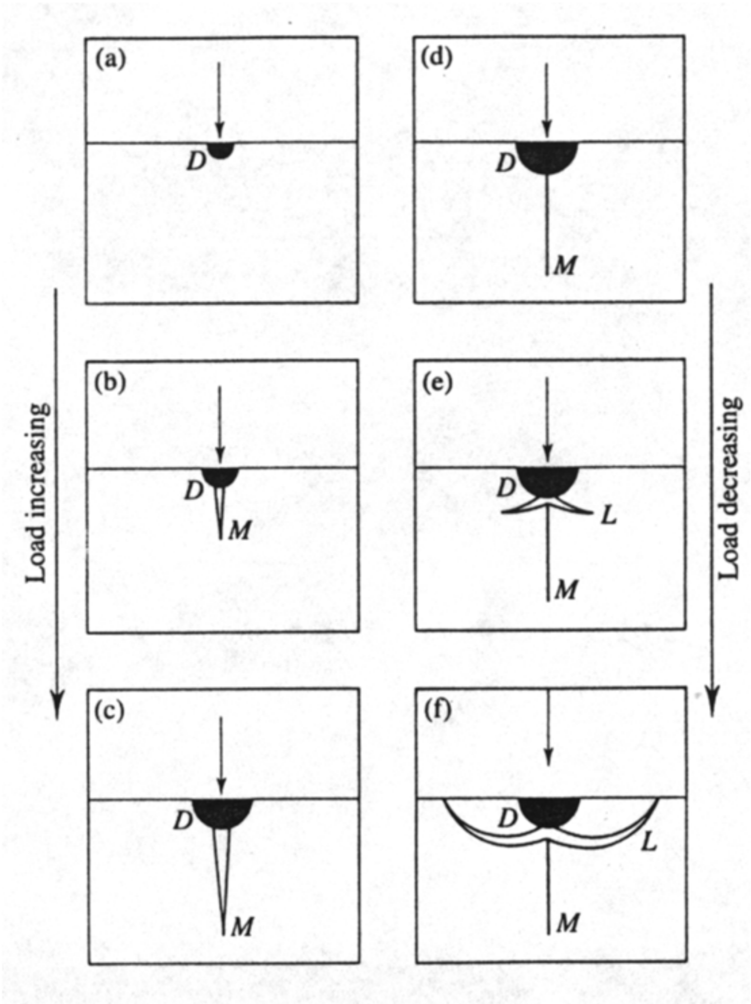

Figure 18. Formation of crack on brittle material (Lawn and Swain, 1975)

Material wear observed in the surfaces analyzed under electron microscope are in these manners; breaking of pieces by breaking of lateral cracks in parallel with the surface, big cracks resulting from breaking of grains on the surface, breakages resulting from uniting of other cracks and radial cracks and cutting movement that produce chip like metals. Formation of mechanism is proportionate to the load on abrasive grain. If load affecting abrasive grain is little, plastic micro cutting or escalloping mechanism is dominant. Surface that is formed with this process is very remarkable with it smoothness. Plastic micro-cutting movements cause creation of chip. If big loads affect discs, brittle cracks are formed on the surface. The most common types of material loss that is caused by brittle cracks are –as mentioned before- lateral crack breakings, breaking of grains on the surface and breaking of pieces from the surface in the shape of spalling. In order to understand the mechanism better, the model developed by Chandrasekar and Farris (1987) is given in Figure 19.

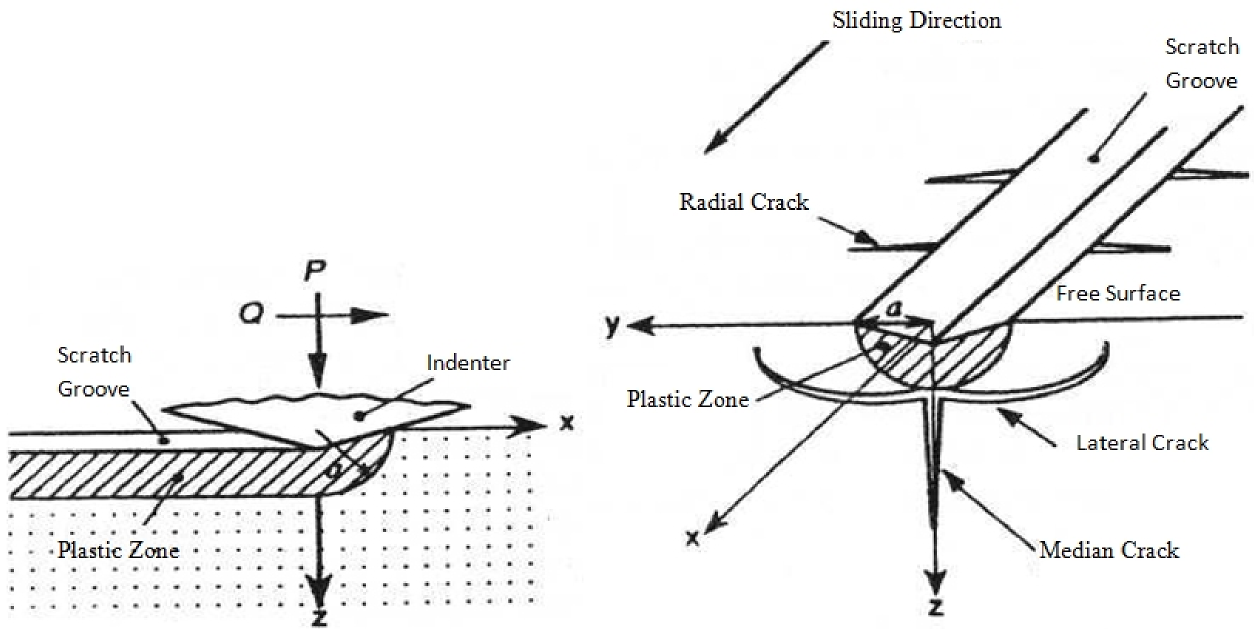

Figure 19. Slipping of grinding indenter on brittle surface and schematic demonstration of fracture after the process

Here, it is thought that one single abrasive grain slipped over the surface and groove. Normal load is very low and groove following a permanent change in the shape without breaking. It is assumed that middle cracks are vertical to the surface and the depth is in direct proportion to the size of normal power applied on abrasive grain. Middle crack starts to unite with lateral cracks in parallel with the increase in normal power. At high loads, lateral cracks are broken and cause material wear. Again at high loads, scratches break along the middle crack and material wear occurs. A similar model is developed by Regiani et al. (2000) (Figure 20).

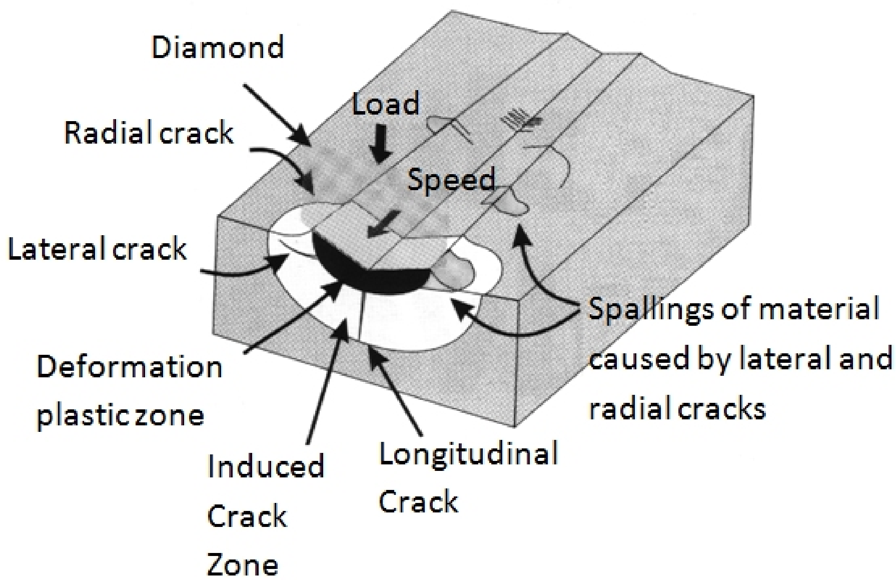

Figure 20. Cracks on the surface formed during abrasion (Regiani et al., 2000)

According to Regiani et al. (2000), basic mechanisms in material wear are; grains breaking, smashing, formation of ductile chip, and spalling. Wear of these types of materials are affected from various variables. Viscosity of used liquid, applied force on the disc, type of the disc and small scaled form of the material that is abraded are the most important of these. Small scaled form of the material has a significant effect on the development of crack that is formed as a result of abrading.

Regiani et al. (2000) stated that small scaled formation whose shape and crystal lengths of crystals that form the material are more enduring to wear than homogenous small scaled formation whose shape and whose crystal grains' lengths are similar. Again, according to Regiani et al. (2000), intrusion, gaps and crystal grain limits behave like borders for crack progress at each type of abrading process. Used liquid, size and type of disc have the secondary importance in removing material.

As a result, volumetric wear according to different operations haven't been revealed yet. Complete understanding of wear will enable the development of productive abrading processes that will create smooth surfaces.

7. Wear and polishing mechanism formed in the use of sandpaper

It is the name of grinding product formed as a result of covering abrasive grains on sandpaper, paper or on a cloth with a binding agent. Sandpaper is widely used for abrading and polishing of surfaces that are made of metal, glass, porcelain, stone, wood…etc. materials.

When glass machine profile is analyzed, it will be seen that abrading is done with abrasive grains that are lined at different positions. Effective factors in abrading process are; disc grain shape, solidity and height, its angle to the surface, applied load and form of bonding material and so the life of paper.

Contact angle of abrasive grain and surface is the most significant effective factor on wear as is given in the definition of adhesive wear.

Abrasive grains make cutting, friction and break through movements in different amounts according to the edge structure and location. Most of the studies focus on chip formation with cutting and occasions according to this.

Chip on the surface that is created by abrasive grain is given in Figure 21 in a simplified way.

In Figure 22, chip formation on brittle material is presented. Simplified chip formation model show that change of shape generally occurs in narrow space at shear plane or in an area called shear area (Figure 21). Permanent change of shape is complex in this area. But it is probably in the shape of hydrostatic component tensile type that will stay on the new surface. Namely, crack that will enable the formation of new surface is tension crack.

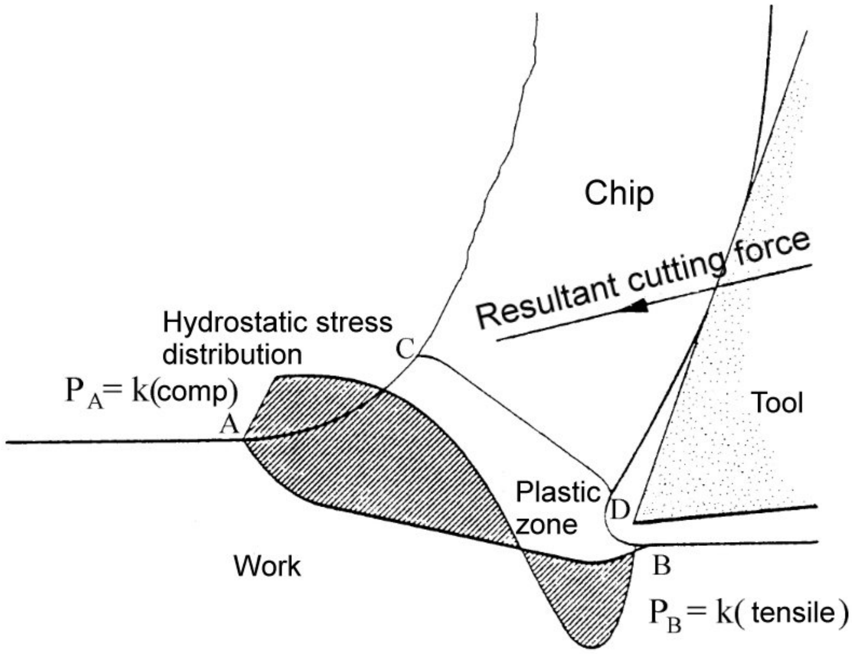

Figure 21. Chip formation model (Samuels, 1971).

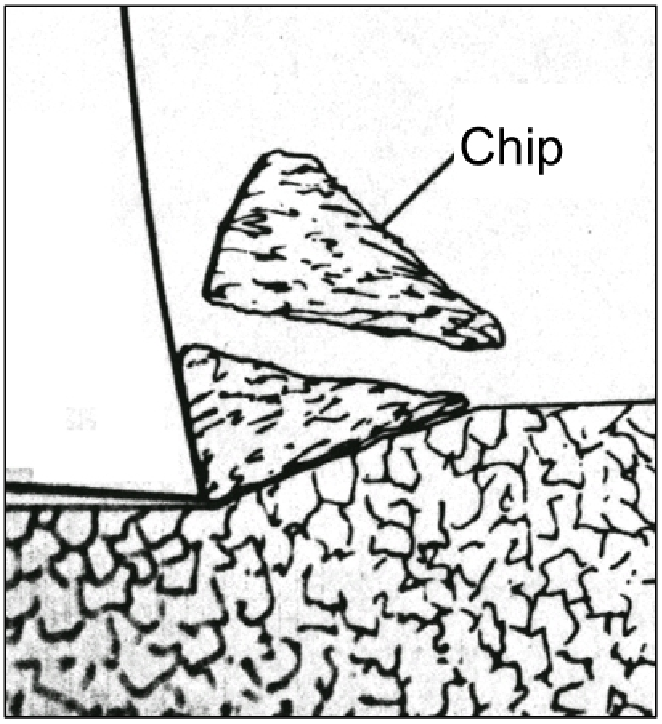

Figure 22. Discontinuous chip creation on brittle material surface (Boothroyd, 1975)

According to Boathroyd (1975), contact angle between abrasive grain and surface is very significant in the process of abrading in order to determine chip formation. on the other hand, deformation distribution of chip area is also affected from this contact angle.

As a result, there is a limiting contact angle for abrasive grains and grinding tip cuts a chip on this angle while it grooves under it. When abraded surfaces are analyzed, it was seen that very few of the scratches are formed as a result of cutting of material in the shape of chip (Samuels, 1971). Abrasive grain grooves on contact points on material surface mostly by breaking through and friction but it removes small amount of material. Very few of them create chips with grating movement and this is more effective in removing material.

Rapid material wear is ensured by applying high loads and low decreasing speed in proportion to high amounts of cutting points, namely by low wear speed of sandpaper. These factors ensure high abrading speed and prevent formation of smooth and shiny surface.

Another intended purpose of sandpaper and cloth is polishing. Mechanism in polishing process is in fact very similar to abrading. It can be said that force affecting each abrasive grain determines depth and width of scratches on the surface of basic material. So, in order to make polishing operations on abraded surfaces, very low loads should be applied on abrasive grain and abrasive grain's height should be very low. Although sandpaper is used in the first step of polishing that is made with sandpaper, polishing cloth (Figure 23) is used in the last step in order to lessen the scratch depth and form shinier surfaces.

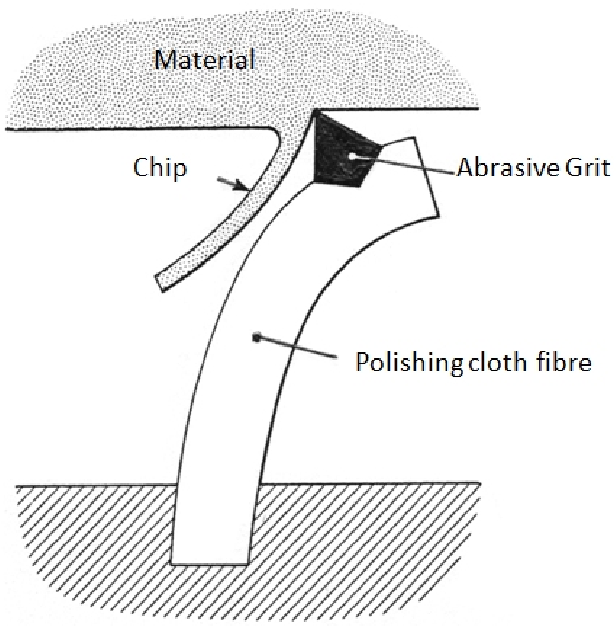

Figure 23. Mechanical polishing mechanism of abrasive grain that is clung on the polishing cloth fibre

As can be seen in Figure 23, abrasive grains in polishing cloth is inside the fibers of cloth. Grains affect on the material surface only with elastic force and ensure the creation of narrower and shallow scratches. In this way, shinier surfaces are achieved.

Author details

Irfan Celal Engin
Afyon Kocatepe University, Engineering Faculty, Department of Mining Engineering, Afyonkarahisar, Turkey

8. References

[1] Archard, J.F., 1953, Contact and Rubbing of Flat Surfaces, Journal of Applied Physics, 24, pp. 981-988

[2] Beilby, G., 1921, Aggresion and Flow of Solids, Macmillan, London.

[3] Boathroyd G., 1975, Fundamentals of Metal Machining and Machine Tools, Scripta Book Company, Washington D. C., pp. 64-106.

[4] Bortolussi, A., Ciccu, R., Manca, P.P. and Massacci, G., 1994, Computer Simulation of Diamond-Wire Cutting of Hard Rock and Abrassive Rock, IMM, Vol. 103, August, pp. A55-A128.

[5] Bowden, F.P. and Hughes, T. P., 1937, Proc. Roy. Soc., p. 575

[6] Chandrasekar, S. and Farris, T.N., 1997, Machining and Surface Finishing of Brittle Solids, Sadhana Acad. Proc. Engineering Sci.,, Vol 22, pp. 473-481

[7] Chen, X. and Rowe, W. B., 1996, Analysis and Simulation of the Grinding Process. Part 2 Mechanics of Grinding, International Journal of Machine Tools and Manufacture, Vol: 36, No: 8, pp. 883-896.

[8] Coes, L., 1971, Abrasives, Springer-Verlag, New York, p. 177

[9] Kato, K., Hokkirigawa, K., Kayabo, T. and Endo, Y., 1986, Three Dimensional Shape Effect on Abrasive Wear, Journal of Tribology, 108, pp. 346-351

[10] Konstanty, J., 2002, Theoretical Analysis of Stone Sawing With Diamonds, Journal of Materials Processing Technology, Vol. 123, pp. 146-154.

[11] Lawn, B.R. and Swain, M.V., 1975, Microfracture Beneath Point Indentations in Brittle Solids, Journal of Material Science, 10, pp. 113-122

[12] Moore, D.F., 1975, Principles and Application of Tribology, Mechanical Engineering Publication Limited, London, pp. 176-186

[13] Ozcelik Y., Kulaksiz S., Cetin M.C., 2002, Assessment of the wear of diamond beads in the cutting of different rock types by the ridge regression, Journal of Materials Processing Technology, 127 (2002), pp. 392-400.

[14] Regiani, I., Fortulan, C. A. and Purquerio, B.M., 2000, Abrasive Machining of Advanced Ceramics, IDR, 1/2000, pp. 37-65

[15] Salmon, S. C., 1992, Modern Grinding Process Technology, McGrawHill Inc. pp 83-101

[16] Samuels, L.E., 1971, Metallographic Polishing by Mechanical Methods, American Elsevier Publishing Company, Inc., Newyork, 224 p.

[17] Suh, N. P. and Saka, N., 1978, Fundamentals of Tribology, Proceedings of the Internatıonal Conference on the Fundamentals of Tribology, M.I.T. press, pp. 400-405

[18] Summers, J.D., 1994, An Introductory Guide to Industrial Tribology, Mechanical Engineering Publication Limited, London, pp. 176-186

[19] Wang, C.Y. and Clausen, R., 2002, Marble Cutting with Single Point Cutting Tool and Diamond Segments, International Journal of Machine Tools & Manufacture, Vol.42, pp.1045-1054.

[20] Williams J.A., 1994, Engineering Tribology, Oxford University Press, New York, pp. 167-199.