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RESEARCH ARTICLE

# Optimal opportunities at stone machining processes done by diamond tool

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***Abstract***

*Different types of stones are used in wider and wider range to produce covers,pavements, tiles, statues, souvenirs. Manufacturers are trying to satisfy the growing demandswith the help of the automatic machines of stone machining. One of the possible solutions to increase productivity is to optimize the stone machining processes. To realize optimization one needs to know the processes of stone machining, the factors affecting machining and the tool wear mechanism. Aim of the first phase of the research introduced in this paper is to create an overall knowledge of stone machining, highlighting the stone cutting process with disc. After acquiring the knowledge the next step is to execute the researches optimizing the stone machining processes.*

***Keywords***

*stone machining · cutting · productivity · optimization · diamond tool*

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## 1 Introduction

Numerous stone types are used in building industry according to the special hardness, strength and ergonomic requirements. The most common stone materials in building- and decorative stone industry are limestone, marble and granite. Different stone materials used in industry have a general distinguishing feature is that their contexture is not homogeneous. Realization of stone machining needs a more complex system because of the inhomogeneous contexture, than machining of homogeneous metal materials.

Thus, machining of stone material is an extremely complex problem. During designing of machining the first aim of the production engineer is to find the most appropriate rate between tool life, economy of machining and the technological parameters. Optimal solution can only be found, if the engineer knows the machining process in details and the factors affecting the process.

In the case of harder stones it is worth to use diamond tool that works appropriately in more powerful machining conditions. It is needed to be taken into consideration that the production costs of larger and stronger tools are higher. Besides production cost, technological parameters used by the tool, application and intensity of cooling and features connecting to machine tool is also important. Production engineer has to know the process coming from the interaction of the tools and the work piece during stone machining to be able to choose the appropriate technological parameters for the special machining process. With these information researchers can develop models that determine the technological parameters and features, which belong to the given machining environment in advance.

This paper briefly summarize the parameters affecting the stone machining process, diamond disks characteristics that realize the hard stone types production, furthermore those basic researches that achieved important results in modelling stone machining process.

## 2 Parameters affecting stone mahining process

During stone machining numerous parameters are needed to be taken into consideration to achieve appropriate efficiency, tool life and productivity. Diamond is almost the single tool material to machine harder stones. Diamond disks implement the cutting of stone blocks into cubes and rectangular. The statue-shaped surfaces are also produced by disks and milling tools. Ersoy et al [3] are introducing the system of the parameters affecting stone machining that is more detailed, than t he one in this paper. During the machining of the stones as a result of the work piece-tool interaction the following phases periodically implement:

1 Penetration of diamond increases the pressure influencing the stone

2 Diamond increases the pressure until the initiation of fracture

3 Diamond grain removes the chip because of the fracture

The affecting parameters of stone cutting can be divided into groups and with the knowledge of these parameters productivity and tool life can be increased (Fig. 1).

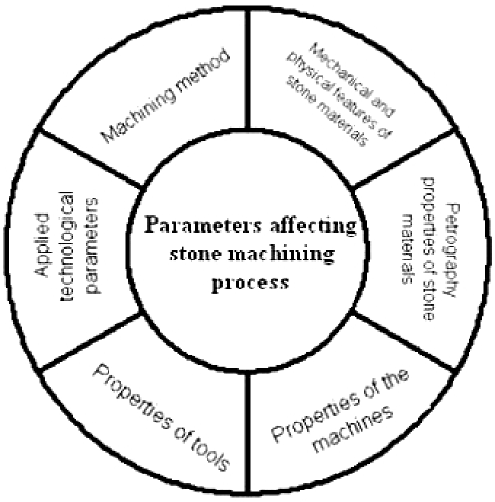


**Fig. 1.** Parameters affecting stone machining process.

### 2.1 Mechanical and physical features of stone materials

Mechanical and physical features of the stone piece greatly influence the machining process. Minerals in the stone affect the machining and also the diamond stone in different ways. Other parameters affect forces between the diamond and the work piece, stress distribution in the stone and temperature between the tool and the work piece [3].

One of the most important properties of stones is strength. Strength is a resistance against an external mechanical effect. Strength can be defined with the highest stress or energy that the stone material can bear without damage. Strength of stones is defined by compressive strength most of the times. In case of cutting processes the impact strength is also really important because during the machining process the stone material is influenced by cycle impact stress because of the continuous contact with the tool [11].

Hardness is also a really important physical stone property. In a case of stone cutting processes Mohs hardness sequence is generally used to determine the degree of hardness of minerals [12]. The essence of this system is that minerals with greater number can scratch the minerals with smaller number in all cases. Shore Scleroscope hardness test is also a common solution of hardness testing. The essence of this solution is that a diamond inserted hammer is being dropped on the test stone in a curved path and the hardness is calculated from the rate of recoil. Another essential parameter is abrasivity that decisively affects the machining process. Appropriate tool material and technological parameters must be chosen according to the wear properties of stones. A relatively abrasive material needs to be cut with a completely different technology than a less abrasive material, like marble.

### 2.2 Petrography properties of stone materials

One of the biggest problems at the machining of stone with diamond tool is that the stones generally have not got homogeneous contexture. It is true for almost every type of stones in building industry that they consist of several mineral types and their distribution and density in given areas of these minerals is not permanent. According to the previous sentences, in a case of stone machining the properties of minerals that build up the stone materials and the average weight percent of minerals of stones need to be taken into consideration. The inhomogeneous contexture also means that the researchers can not create so detailed algorithm that is able to completely model the stone machining process. Reason of this statement is that the minerals of stones take place randomly inside the stone.

Maximal and average size range of grains of minerals that build up the stone is a common measure at machining tests. There is a close connection between this property and the relative frequency of the given mineral type in the stone. Quantity number of the minerals is defined by Streckeisen diagram. Measurement solution for classifying igneous rocks is a diagram based on the relative quantity of mineral phases in stones.

Measure of binding force between each mineral is an other important petrography property that influences stone machining. It is easy to accept that in a case of materials with harder binding it is harder to detach each grain from the surface and because of this we need to use stronger technological parameters and harder tools.

### 2.3 Applied technological parameters

Technological parameters used in cutting process greatly influence the efficiency of stone machining and the wear process of the tool. During milling and cutting the same three technological parameters determine the efficiency of machining.

Feed ($F$) defines the orbital velocity of the tool. Dimension of feed is mm/min. On the same rotational speed when feed rate is higher the edges of diamond tool (single diamond grains or covered inserts) detach more material in a given time range.

Rotational speed is also an important parameter. Rotational speed defines how many revolutions are needed to be made by the tool. In case of higher rotational speed the quantity of chip detached by the cutting edge decreases and as a result of this a more advantageous wear rate can be reached.

Third general affecting parameter is the depth of cut. The life time of the tool can be greatly increased with choosing the appropriate depth of cut. During stone machining when the depth of cut is higher the impact forces are higher during the machining and because of it the opportunity of breaking of the diamond grains increases.

Naturally other parameters also influence the efficiency of stone machining but the literature that studies the cutting and machining of stones highlight these three parameters.

### 2.4 Properties of tools

In case of all materials the appropriate tool choice is really important from the point of view of efficiency of the cutting process. This fact is also true by stone cutting and milling.

Diamond tools are used on a large scale to machine hard stones. During milling processes it is very important to choose the appropriate size (for example diameter) tool but also important the appropriate choice of insert cover. It is also essential to apply appropriate insert angles from the point of view of the forces.

In case of stone table cutting typical properties of the disk is diameter, material and type of segments, and concentration and size of diamond grains in the segments. Wear process can be sped up by applying inappropriate grain size or grain density or when we choose too strong tool to the process we generate unnecessarily high tool costs.

### 2.5 Properties of the machines

Beside the appropriate tool choice and technological parameters it is really important to apply a kind of machine during the stone machining process that is needed to the stable and effective process. One of the most important machine- parameter is the maximal power per unit that the machine can lead. We work in vain with given technological parameters and tool if the machine can not satisfy the generated power requirements. In case of every machining process, even by stone cutting, stiffness is a very important feature. When the machine unit has low stiffness, harmful vibrations are generated and as a result of the vibrations, inadequate surface quality and in extreme case tool fracture is also can be occurred. As a result of the first case an inappropriate piece is produced for the demands of the customers while in the other case serious damages are possible.

### 2.6 Machining method

During cutting and milling process equally two machining methods is distinguished. There are significant differences between the two strategies in the area of nascent forces. The two machining methods are compared by the cutting process of the stones.

Diamond grain fully penetrates to the material at the moment of the collision during the down-cutting process. This machining method results maximum thickness at the beginning of cutting process and because of it the forces that affecting the grains are high. According to the previous sentence, during the machining of hard stone types, like granite, as a result of the impact loads the grains fracture and/or drop out from the matrix. This effect ruins the diamond tool in a short time.

In case of up-milling the diamond grain in the moment of the collision with the work piece starts detaching minimal chip thickness. This chip thickness grows during the material cutting while the diamond grain is crumbling and wearing. Advantage of up-milling strategy is the more favourable wear process and the drawback of up-milling is that a particularly high stiffness machine is needed for the appropriate application [1].

## 3 Applied tools

During stone machining, especially when hard materials are machined, tools with diamond cover or diamond grains are used. During the machining process almost all of the tools are equipped with inserts. Tool becomes useable for more stone types. In addition in case of wearing it is enough to change only the inserts and the tool body that means high costs can work on.

This paper highlights stone table cutting and we describe the structure and the application opportunities of cutting disks with diamond grains in details.

### 3.1 Diamond cutting disks for general application

The result of relative movement of diamond tool-grains and the hard work piece is stone machining. Traditionally used tools are built up of diamond grains that take place in a metal matrix. This matrix connects to a metal stem or in other words, to a steel core [6] (Fig. 2).

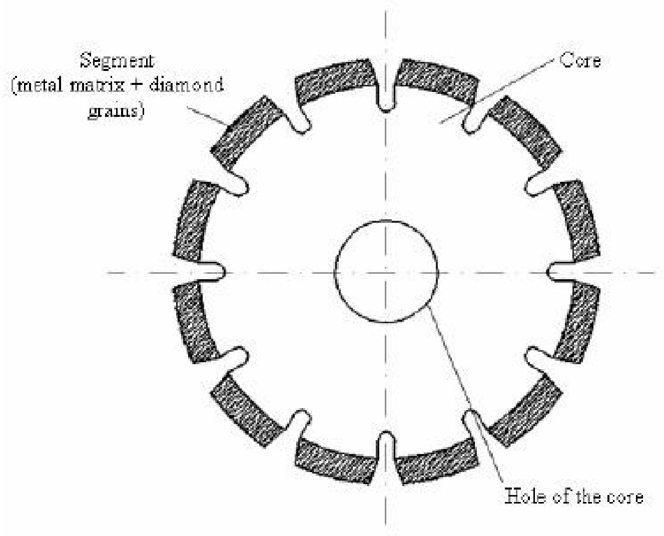


**Fig. 2.** Parts of the diamond disk.

Steel cores are made of different quality of steels that depends on whether the segments are soldered or welded to the core. Steel core are hard and hardened approximately their hardness is 43-45 HRC. Final shapes of the cores are generally produced by laser cutting or milling. The hole in the centre of the core is made by honing. Requirement for the hole is extremely low tolerance and excellent circularity-tolerance. Exact core diameter and perfect geometrical shape is also an essential requirement [6].

Metal matrix is responsible for the cutting. Diamond grains can be found in the matrix.These diamond grains detach the parts of the work pieces because of the connection with the work piece. Typical matrix materials are cobalt, copper, nickel and iron. The diamond grains have to take place in the matrix in a way that the tool has to have same machining properties and efficiency during the whole life time of the tool. As a result of these requirements vibration machines are used by producing matrixes that mixing the matrix materials with the diamond grains and with this method they can ensure the random layout. Afterwards the mixture of diamond- and matrix material grains is sintered by cold mangling or laser welding [6]. Cutting disks have two basic forms: Disks with continuous edge and tools with segments.

Application of disks with continuous edge comes into view when relatively high surface quality is needed. During stone machining with segmented disks worse surface quality but longer tool life time can be reached as the generated stone brakeage can leave free between the gaps of the segments. Thus chip will not accumulate in machining zone.

### 3.2 Principle of wear of cutting disks

In case of producing design task one of the possible objective functions of the produce engineer is the pursuit for cost minimization. Cost minimization is parallel to economical tool mode. This mode is parallel to the wear rate. During stone machining with traditional milling cutters similar systems of equations and solutions can be used to achieve objective function, like during metal machining. When stone blocks are machined by diamond disk another philosophy is needed to be followed. Base of this philosophy is the speciality of the wear process of diamond disks.

Speciality of wear process of cutting disks is that during the machining process two wear processes is also generated. This mechanism is the wearing of the grains and the matrix. To minimize tool wear it is necessary to modify the objective function. The modifications is that instead of minimal wear it is needed to find the matrix-diamond pairing with that the two wear mechanism can be realized in similar extent. Inappropriate pairing can cause two direction problem. In one of the cases the wearing of the matrix will be larger scaled than the wearing of the diamond grains. In this case the diamond grains fall out of the surface of the matrix before they can wear out. Thus the wear rate greatly increases since the dropped out grain could have been used. Reverse case is when the wearing of the grains is higher than the wearing of the matrix. Then the worn out grains do not fall out from the surface of the matrix in time. Furthermore the new, sharp diamond grains do not come to the surface because of the low matrix wearing. Therefore after a while the matrix material will establish direct connection to the surface of the work piece that significantly deteriorates the efficiency of machining.

Because of the previously described principle it is really important to find the appropriate matrix-grain rate with which the tool can work with appropriate efficiency and minimal wear rate.

## 4 Research trends in this topic

The aim of the first phase of the research in this paper was to create a summary documentation which can be used as a source material for the next phases and tests of the researches. In the first phase I have examined what kind of trends exist nowadays in the area of optimization of stone machining process. The limited size of this paper does not make it possible to introduce all of the trends in details but I have summarized the three most important ones.

### 4.1 Effects of properties of stone materials

In the previous chapter of the paper, it was mentioned that stone machining is an extremely complex problem. One of the main elements of the problem is the inhomogeneous contexture of different stones. While metal materials can be considered to have a homogenous contexture, different machined stones -like granite, marble and limestone- most of the time have an inhomogeneous contexture. Different types and sizes of minerals make up the stones. In most cases there are important differences between the sizes of same-type mineral grains. In recent years there has been research on what parts of stones are. The most responsible for the nature of tool wear processes and for efficiency of machining.

Yilmaz et al [10] were searching for the properties of stone materials that mostly influence the wear process of tools in the case of "real" granite machining. 9 different types of real granite and 3 types of granite that is available commercially but not real granite types are used for the researches. The research included the examination of the contexture of stone materials, mineral composition, size of grains and the distribution of grains. The same samples were also examined based on physical and mechanical properties. Statistical analysis of experimental data showed that the most dominant parameter in case of wear process of diamond cutting disks is the maximum size of mineral grains of quartz and alkali feldspar (microcline and orthoclase). They pointed out that other feldspars, like albite or oligoclase can influence the wear rate in a small compass. During examining physical and mechanical properties they established that Shore-hardness is the only parameter that can greatly affect tool wearing. In the end of the researches they defined an empirically calculated value of wear rate that can be effectively applied in the case of real granites to anticipate wear rates.

### 4.2 Examinations about force and power tests

Models that work with force measuring and power calculating in the area of examination of stone machining can be found in several literatures and research reports. Basic of several researches is the fact that tool wear during stone machining can be directly associated with forces and energy consumption during cutting.

Turchetta alone or with his colleague wrote several publications and the centre of these is the examination of force tests and energy consumption [5–8]. Dynamometer that is located in the direct area of machining is used for force measuring in each case. With dynamometer he was able to measure the components of machining force that is parallel or reverse to the tool movement. During researches he was interested in how force components of machining depend on the applied technological parameters, in other words on feed rate of depth of cut. Turchetta and Pollini examined in their paper if acceleration measuring sensor can also be applied over force measuring for the examination of tool wear process. As a result of the researches they developed a model based on force measuring that can help to define the forces during the process and the used energy in advance. He also used the result that machining force and the used energy can be associated with the applied technological parameters, feed rate and depth of cut. A multi-sensored measuring system was assembled by him and with the help of this he compared acceleration and force measuring. As a result of the comparing he made the conclusion that with the examination of acceleration the force- and energy values can be estimated with similar efficiency.

### 4.3 Comparative analysis

Comparative analysis is a general research method when the researchers compare two algorithms, mechanisms or process. Comparative analysis means also an effective solution in case of stone machining. In the literature several analyses can be found about comparing tool materials [9] or examining machining strategies [1].

During his research Buyuksagis [1] examined the two machining methods that are generally applied by stone block cutting. These methods are down-cutting and up-cutting and the examined the effects of them with regard to the efficiency of machining process and wearing process of the cutting disk. During the researches they examined the effects of machining methods in case of 6 different granite types. They measured the wear rate of the disks before and after each test sequence. Not only did they examine wearing but they also measured and saved the amount of used energy in each process. Machining tests were done on a highly accurate block-cutting machine. Measuring instruments included a displacement meter, a rotation measurer and a digital energy meter. In the case of all tested granite types it was confirmed that the tool wear rate and the used energy is lower during upmilling than during down-milling. Results of the experiments showed that high energy consumption comes with high tool wear rate.

## 5 Conclusion

The aim of the first phase of researches in this paper was to create a summary documentation within trends and results of researches on the optimization of machining different stone types can be found.

This paper briefly summarizes the parameters that affect the stone machining process, the structure and the speciality of the wear process of stone cutting tools. Furthermore it particularly highlighted three main research trends in the area of stone machining increasing efficiency.

In the next phase of the research it will be examined which trends need further examination and in what area free research capacity can be found yet.

## References


1 **Buyuksagic IS**, *Effect of cutting mode on the sawability of granites using segmented circular diamond sawblade*, Journal of Materials Processing Technology **123** (2006), 146–154.

2 **Di Ilio A, Tonga A**, *A theoretical wear model for diamond tools in stone cutting*, International Journal of Machine Tools & Manufacture **43** (2002), 11.

3 **Ersoy A, Buyuksagic IS, Atici U**, *Wear characteristics of circular diamond saws in the cutting of different hard abrasive rocks*, Journal of Wear **259** (2004), 1422–1436, DOI 10.1016/j.wear.2004.09.060.

4 **Konstanty J**, *Theoretical analysis of stone sawing with diamonds*, Journal of Material Processing Technology **123** (2002), 146–154, DOI 10.1016/0924-01360(02)-00071-7.

5 **Polini W, Turchetta S**, *Monitoring of diamond disk wear in stone cutting by means of force or acceleration sensors*, Int. Journal Advances Manufacturing Technology **35** (2007), 454–464, DOI 10.1007/s00170-006-0733-x.

6 **Tönshoff HK, Hillmann-Appmann H, Asche J**, *Diamond tools in stone and civil engineering industry: cutting principles*, Key Engineering Materials **250** (2002), 103–109, DOI 10.1016/S0925-9635(01)00561-1.

7 **Turchetta S**, *Cutting force in stone machining by diamond disk*, Advances in Materials Science and Engineering **2010** (2010), DOI 10.1155/2010/631437.

8 **Turchetta S**, *Cutting force on a diamond grit in stone machining*, Int. Journal Advances Manufacturing Technology **44** (2009), 854–861, DOI 10.1155/2010/631437.

9 **Turchetta S, Carrino L, Polini W**, *CVD diamond insert in stone cutting*, Diamond & Related Materials **14** (2005), 641–645, DOI 10.1016/j.diamond.2004.10.031.

10 **Yilmaz NG, Goktan RM, Kibici Y**, *An investigation of the petrographic and physico-mechanical properties of true granites influencing diamond tool wear performance, and development of a new wear index*, Journal of Wear **271** (2011), 960–969, DOI 10.1016/j.wear.2011.04.007.

11 **Török Á**, *Geológia mérnököknek*, Műegyetemi kiadó, Budapest, 2007.

12 **Gálos M**, *Kőzetvizsgálat és minősítés*, Budapesti Műszaki Egyetem Továbbképző Intézete, Budapest, 1976.