MICRO CUTTING SIMULATION OF ABRASIVE GRAINS IN THE GRINDING PROCESS

Abstract: In the current work we present approach to study the mechanism of the cutting of abrasive grains in the grinding wheel using finite element analysis (FEA). The simulation process is done by separating two abrasive grains from the grinding wheels and the microprocess of material removal in the case of surface grinding is simulated. Modelling was done on the workpiece steel S-7 and material grain is SiC. Simulations of abrasive grains in the grinding process are performed by different conditions. Workpiece and abrasive grains are modelled using CREO Parametric software, and micro cutting simulation are done using ANSYS. Defining a finite element mesh, cutting regimes and material characteristic provided a temperature analysis with a lot of details and also an appearance of the grinding process.

Key words: grinding modelling and simulation, finite element analysis, micro cutting temperature

1. INTRODUCTION

Grinding is a highly precise manufacture process with the material removal applied in the various machine parts processing. Primarily it is applied to the finishing processing of the hard surfaces of the flat, cylindrical and complex shapes.

On the other side, the grinding process represents one of the most complex cutting processes. The complexity of the grinding process is caused by the simultaneous cutting of a large number of grinding grains uneven and undefined cutting geometry, which is constantly changing during the grinding process. In addition, unlike others processing methods with defined cutting geometry, there is no possibility to have a constant contact of the grinding grains with the workpiece during the grinding process. [1,2].

The cutting process of the grinding is achieved by a large number of grinding grains simultaneously process a very thin layer of a material. In that way, a large amount of micro chip is formed and it is placed between two adjacent grinding grains. When the grinding grains lose the contact with the material, the chip leaves the area by the influence of the centrifugal force or due to the cooling and lubricating liquid.

Even the grinding process is very difficult to analyse, the average shape of grinding grain can be isolated and through that grain the general mechanism of grinding process can be described, Figure 1. During the active cutting by the grinding grain the thickness of the cutting layer $h_{eff}$ is changing from zero to the maximum value. The process of the grinding grain acting to the workpiece material can be conditionally divided into 3 characteristic phases. In the first phase the grinding grain penetrates into the material and it comes to the elastic deformation of the material. In the second phase plastic deformation and the flow of material are realized. The second phase lasts until the grain penetrates to a certain depth in the workpiece, when the real chip formation begins. In the third phase simultaneously comes to material extrusion and chip forming. How many the material of workpiece will form the chip, and how many will be pressed, depends on the geometry of the grinding grain and the elements of the grinding mode. [3,4].

Fig. 1. Phases of chip formation in grinding [3]
Beside the elastic and plastic deformation, all 3 phases are accompanied by great friction between the surfaces of the grain and material. Therefore, it can be argued that the grinding process represents a mixture of the productive cutting (chip formation) and unproductive cutting (workpiece surface friction). If during the grinding process unproductive cutting prevails, a large amount of heat is developed, resulting in intense wearing of the working surface of the grinding wheel and it worsens the processing quality.

2. GRINDING TEMPERATURE

Intense heat generation and difficulty of its evacuation from the cutting zone leads to creation of high grinding temperature and can result in high thermal load of wheel and workpiece. This thermal load, mainly of workpiece, is a boundary condition for a further development of grinding process [5-8].

The study of thermal phenomena during the grinding process dates back to the mid-twentieth century. In the initial phase, this area of science about material removal primarily relied on experimental tests and theoretical analyses until the end of the ’70 when the mathematical process models are begun to be used which are solved by numerical methods.

Past years, the numerical methods, especially finite element method (FEM), becomes the main procedure in the simulation of metal cutting. Recently, programming systems are developed based on the finite elements method, which are only intended for the simulation of cutting process. Among scientists, that have examined this problematic couple of them have made quite interesting results [9-11].

3. FINITE ELEMENT ANALYSIS

Computer application has brought revolutionary changes in the field of different engineering and scientific disciplines, and one of the first was the mechanics of the solid bodies. In the number of computer calculation methods, created in the past four decades, the most widely accepted and developed is the finite element method (FEM), which, in its present form, dates from the late 1950’s. Theoretical basis of the method are set by Hrenikoff (1941) and Courant (1943) and Levy is creditable for the first application of triangular finite element for the study of plane stress on one airplane construction [12].

The latest period of development is marked by the appearance of the FEM system working with discrete elements, thus enabling the simulation of gas flow with high speeds. For the reason of relative complexity of these kinds of problems, those systems are still the subject of interest for the small number of specialists.

Complex geometric shapes and complex loads of supporting and transmission elements of machines cause the complexity of their analysis and calculations. Numerical methods provide a general tool to analyze arbitrary geometries and loading conditions. Among the numerical methods, finite element analysis (FEA) has been extensively used with success; however, this kind of analysis requires the generation of a large set of data in order to obtain reasonably accurate results and consumes large investment in engineering time and computer resources.

FEA is one of the modern methods of numerical analysis. Theoretical basis of the finite elements method are made in 1950’s, but the practical application takes place with intensive computer application. It was created from the need for calculation of stress and deformations, and with development of the method the number of variables that can be calculated within the static, dynamic, thermal, electromagnetic and other analysis is increased.

The FEA simulations are increasingly used for investigating and optimizing the blanking processes. Many time-consuming experiments can be replaced by computer simulations. Therefore, highly accurate results of metal forming may be obtained by using the FEA simulation [9, 13].

4. GRINDING PROCESS MODELS

Grinding process models based on the complex relationship between process and machine parameters, and work results. The interaction is modelled by prediction of grinding forces, temperatures, energies, surface integrity etc., depending on the conditions of the grinding process. These include fundamental approaches as well as kinematic models, finite element method, molecular dynamics, physical and empirical approaches, artificial neural nets, and rule based models.

Due to the large number of abrasive grains with an unknown geometry which varies with time, grinding is a complex material removal operation. This chapter focuses on the prediction of micro cutting temperature occurring during grinding as an input value of process, in order to describe the interaction between the process and the machining conditions.

The large number of input variables complicates the development of a universal model. Due to different contact conditions, several models have been developed accounting for different grinding operations [14].

In this work, due to the impossibility of modelling an enormous number of active grinding grains of the grinding wheels, which are in simultaneous contact with the workpiece, it is modelled the micro cutting of the grinding grain. Figure 2 shows the characteristic grinding grain shapes, as well as the micro mechanisms for material removal. It can be seen that the speed and depth of the material cutting depend on the type of the grinding grain.[3,4].

Workpiece and wheel are modelled using CREO Parametric software, and micro cutting simulations are done using ANSYS. Necessary materials and thermal-physical characteristics are selected from material library of the FEA package. Material for grain is SiC, and for workpiece is Steel S-7. The cutting depth was \( a = 0.05 \) mm, the workpiece speed was \( V_w = 50 \) mm/s and the grinding wheel speed was \( V_j = 30 \) m/s.

Figure 3 shows the grinding grains model and their meshes. The model defines real grain shape with defined cutting geometry.
Micro furrowing:
- energetic very inconvenient
- removal mechanisms

Micro ploughing:
- energetic inconvenient
- removal mechanisms

Micro flow cutting:
- energetic convenient removal mechanisms
- big depth of cut

Micro curled chipping energetic:
- convenient removal mechanisms
- big depth of cut

Fig. 2. Metal removal mechanisms of grinding [3]

Defining the parameters for the micro cutting simulation of abrasive grains in the grinding process includes the definition:
- Grinding model;
- Coordinate system;
- Connection;
- Meshing of the model;
- The wheels speed compared to the workpiece;
- Simulation of contact length in grinding;
- Results selection.

Meshing of the model will determine simulation of the contact length in grinding, but also the accuracy of the simulation. To form a mesh commands Refinement and Face Sizing are used. Using the command Refinement a more realistic and finer tool edge is got.

Fig. 3. Grinding grain model with mesh

In FEA mesh modelling, was used the tetrahedrons method of mesh forming. The top surface mesh is 3 times smaller structure as opposed to the lower surface, what can be seen in Figure 4. The total number of elements is 173,314, and the total number od nodes is 33,543 at the workpiece and grains. This type of mesh has proven to be the most accurate for this type of simulation.

Fig. 4. Modelled mesh at the workpiece preview

5. THE SIMULATION RESULTS,

Fig. 5 shows the micro cutting simulation of two abrasive grains in the grinding process. It can be seen the material removal process after the travelled path of the grinding grains which is more than half of the length of contact with the workpiece. The shades of the blue to red colour graphically represent the temperature in the tested workpiece.

Fig. 5. Grinding simulation of two abrasive grains

Fig. 6 presents the grinding simulation at the beginning and in the course of the process, when maximum temperature in the workpiece is 930 °C and 940 °C, respectively. At the same time the maximal temperature in the removed material is 1,244 °C. It can be noticed that high temperatures occur immediately at the material removal process.

Fig. 6. Micro cutting simulation at the beginning and during the grinding process
Figure 7 shows only the workpiece with hidden grinding grains. At the same time the workpiece is cut lengthwise in order to better display the temperature field.

**Fig. 7. Temperature field of the workpiece section**

6. CONCLUSION

Simulation of grinding is still an academic-driven field of research accounting for many different simulation approaches which today mainly focus on grinding wheel-workpiece interaction inside the contact zone. Conducted simulations primarily help to increase the understanding of a grinding process with its millions of single grain engagements resulting.

From analysis made in this work, it was found that the grinding temperature can be easily tested in this way. Material defects could also be considered, which occur as a result of material production and as a result of machining.

This method of testing would be cost effective in complex assemblies, which are much more expensive to assemble in real world than virtual. Their testing in real conditions would be far more expensive than testing in simulation package.

The results obtained by testing needs to be taken with the material irregularities that are formed during the production of the material, as well as the vibration on all machines.

7. REFERENCES


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