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FEM SIMULATION OF HIGHSPEED GRINDING

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ABSTRACT

The article describes an application of a FEM simulation software AdvantEdge™ by ThirdWave for a high-speed grinding process. The experimental computer simulation solves the influence of abrasive grain wear on the output parameters. Based on the fact that the above-mentioned software has not been primary designed for the simulation of machining by the cutting tools with undefined shape; a grinding grain was substituted by an approximate sharp and worn model. The results showed a surface integrity failure when grinding at 120 m/s by the sharp grain. Experiments have been created in cooperation with Hungarian University of Miskolc, Department of Production Engineering.

Keywords: FEM, simulation, grinding, high-speed, AdvantEdge™.

1. INTRODUCTION

A technological and economic situation in branch of production engineering brings about a quest for the existing processes optimization. A Finite Element Method (FEM) of analysis is suitable for their understanding. The desired results of every single production process can be reached only if fundamental physical processes are clearly understood. The quantitative results can be also gained from a numerical analysis. However, an analytical solution is limited to some extent. Mathematical equations are set up by an application of all known marginal conditions. Unfortunately, they do not solve the problem as the equations are too complicated. For example, the analytical approach to forming operations (a chip formation during metal working) results in unsolvable equations, especially when deformation hardness, and difficult tool and workpiece geometry are considered.

2. SIMULATION INPUT PARAMETERS

After grinding the surface quality and related residual stress in ground layer depend on many parameters of the grinding process. Grinder quality influences deformation characteristics of machine-tool-workpiece system, heat build-up and resulting changes in workpiece material. The simulation of grinding by sharp and blunt tool helps to find a solution of this problem. Thus, the simulation was done by the Third Wave AdvantEdge™ program which is designed for solving problems of metal working. It enables an increase in removed material output, parts quality and tool optimization without necessity of being physically tested. Although the program is mainly used for the simulation of milling, drilling and turning, it is also suitable for grinding when its limits are taken into account.

The simulation was done for optimal state of grinding by one grain. Dependence of deformation, stress and temperature on cutting speed was measured when grinding by sharp and blunt grain. Two possible ways of grinding by blunt grain (0.05 mm and 0.1 mm) were chosen, as well as cutting speeds 30, 60, and 120 m/s. Removed material output was 0.01 mm in all cases. Dulling of grinding grain was determined by a size of a contact area of the grain and material. Table 1 shows the simulation parameters. Workpiece material was chrome steel 100CrMn6 - (CSN 14 209). Length and height of the grinded area (in X direction) were 2 mm.

3. FEM SIMULATION RESULTS

3.1. Influence of cutting speed when grinding by sharp grain on tension formation

If material was grinded by sharp abrasive grain (to ensure functioning of the simulation, roundness r = 0.002 mm was used), values of Von Misses stress were σ = 2407,43MPa for cutting speed v_c= 30 m/s and σ = 2332,3MPa for v_c= 60 m/s. As can be seen, there was a slight variation of the results. Values of the following parameters were: temperature of the workpiece and the tool, press of grinding, generated heat, shear stress and Von Misses stress (Tab.2). When simulating grinding by sharp grain at v_c= 120 m/s the software failed to determine the desired values. The volume model revealed consistency imperfection that resulted in crack – Fig.3. Although the simulation ran through, the data were inapplicable.

Table 1. Simulation Input Parameters

Workpiece	
Material	14 209 – 100CrMn6
Height X Length h x l [mm]	2 x 2
Tool	
Material	CBN
Rake Angle	45°
Relief Angle	45°
Cutting Edge Radius[mm]	0.002
Process Parameters	
Feed [mm/rev]	0.02
Cutting Depth [mm]	0.01
Cutting Speed [m/s]	30, 60, 120
Initial Temperature[°C]	20
Friction Coefficient	0.2
Simulation Parameters	
Method of Simulation	Rapid
Max. Dimension of Element	0.1
Min. Dimension of Element	0.02
Min. Cutting Curve Parameter	0.6
Min. Feed Parameter	0.1
Refining Mesh Factor	2
Coarsening Mesh Factor	6
Max. Number of Mesh Elements	12000
Number of Output Pictures	50

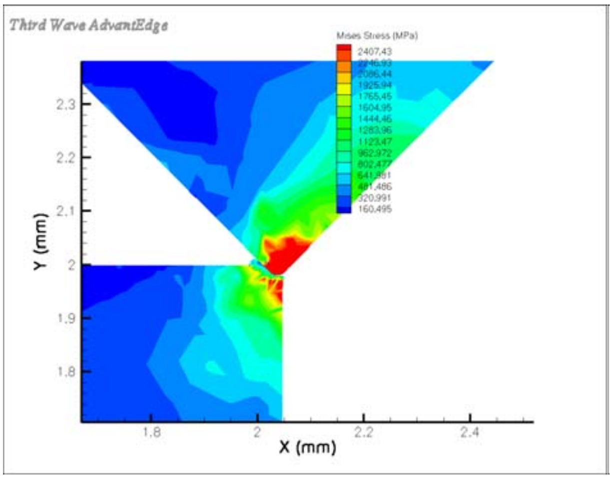

Figure 1. Von Misses Stress gained from grinding by sharp grain at cutting speed 30 m/s

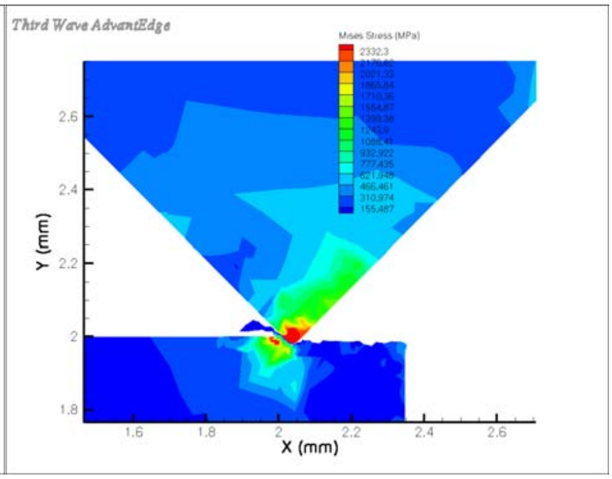

Figure 2. Von Misses Stress gained from grinding by sharp grain at cutting speed 60 m/s

3.2. Influence of abrasive grain wear on tension formation

Subsequently, influence of abrasive grain wear on measured values followed. Shape of the model contact area was altered. Two types of models were created; type 1 – with contact area size of 0.05 mm and type 2 – with contact area size of 0.1 mm. The simulation input parameters remained the same. Measured values were compared to sharp grain model.

The experiment implied that tension locally increased with the grain wear (with the contact area size between abrasive grain and grinded area). According to Fig. 4 Von Misses stress increased twice in comparison to model with 0.05 mm contact area size. On the other hand, this result did not proved the fact that perfectly sharp grain enables the lowest state of tension during the simulation. The temperature at cutting place rose with the increasing cutting speed. When grinding by sharp grain at v_c

= 30m/s, the temperature was 841 ^{o}C and the surface might have been locally tempered into the depth of 0.04 mm.

As was expected, the highest temperature was reached when grinding at 120 m/s by blunt grain with contact area size of 0.1mm. Maximal temperature was 1154 ^{o}C and maximal output of heat (2,23037.10^{7} W/mm^{3}) was reached.

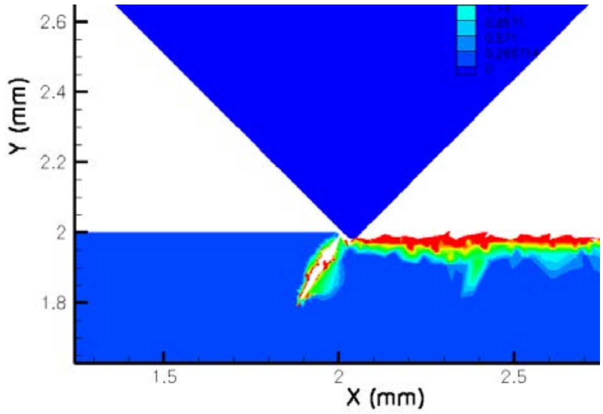

Figure 3. Surface integrity failure when grinding by sharp grain at 120 m/s

3.3. Heat generation during grinding

Grinding is widely used for machining of the surfaces with good dimensional accuracy and quality. Height temperatures between the grain and the workpiece were generated when grinding. Two percents of overall work was consumed for lattice deformation and new surfaces creation. The rest was transformed into heat. Heat was partly carried away by the chips, the workpiece, the coolant (environment) and the grinding wheel. Fig. 5 shows simulation of grinding by one abrasive grain, heat generation and specific heat consumption. The overall of the temperatures is in Tab.2.

Type 1 – contact area 0,05 mm *Type2 – contact area 0,1 mm*

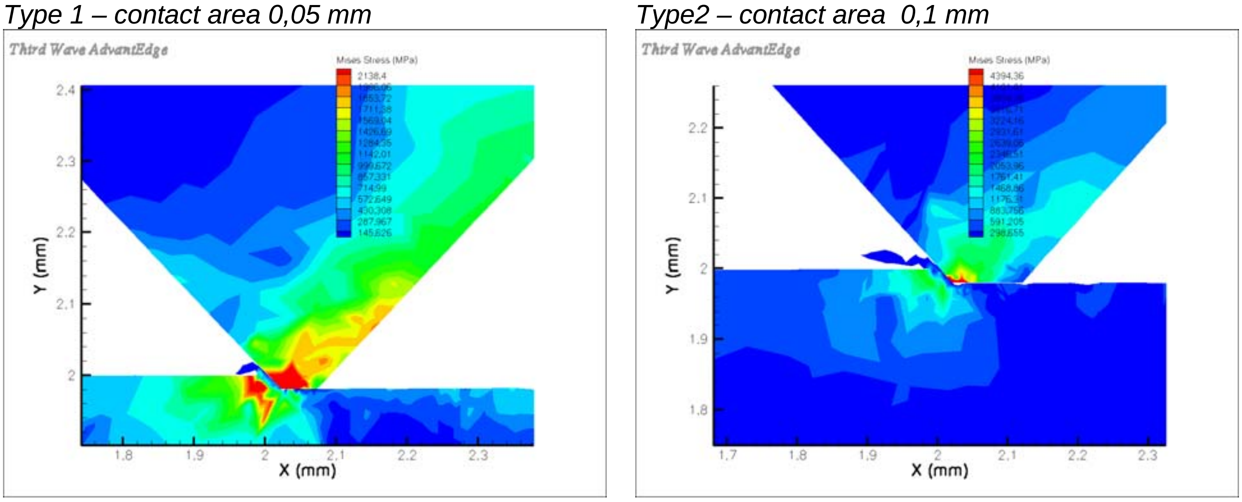

Figure 4. Influence of grain wear on Von Misses stress formation

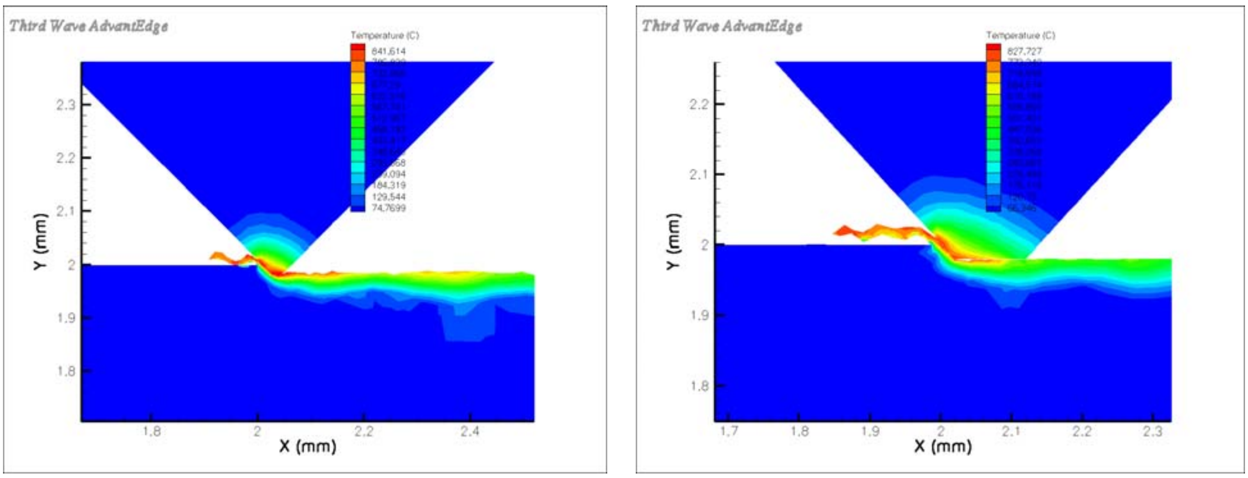

Figure 5. Temperature field when grinding at 30m/s by A) sharp grain (r = 0,002 mm); B) blunt grain with 0,1 mm length of the contact area

Table 2. Simulation Results of Grinding by One Grain

Listed extreme/ maximal value	Abrasive Grain roundness r = 0,002mm	Abrasive Grain Size of Contact area 0,05mm	Abrasive Grain Size of Contact area 0,1mm
Cutting Speed v_c = 30 m/s			
Maximal Temperature	841 ^{o}C	891,83 ^{o}C	827,73 ^{o}C
Generated Heat	$2{,}2.10^6$ W/mm^3	$4{,}5375.10^6$ W/mm^3	$2{,}183.10^6$ W/mm^3
Maximal Generated Press	3443 MPa	3124,5 MPa	3242,7 MPa
Shear Stress	1269,51 MPa	1106,32 MPa	2264,24 MPa
Von Misses Stress	2407,43 MPa	2138,4 MPa	4394 MPa
Cutting speed v_c = 60 m/s			
Maximal Temperature	1072,65 ^{o}C	998,818 ^{o}C	1084,63 ^{o}C
Generated Heat	$3{,}7189.10^6$ W/mm^3	$2{,}867.10^6$ W/mm^3	$7{,}5763.10^6$ W/mm^3
Maximal Generated Press	2713,35 MPa	3289,63 MPa	4072,96 MPa
Shear Stress	1184 MPa	1152,21 MPa	1702 MPa
Von Misses Stress	2332,3 MPa	2175,33 MPa	3487,92 MPa
Cutting Speed v_c = 120 m/s			
Maximal Temperature	Unsuccessful Simulation – See Fig. 3	1522 ^{o}C	1154 ^{o}C
Generated Heat		$9{,}8217.10^6$ W/mm^3	$2{,}23037.10^7$ W/mm^3
Maximal Generated Press		4194,42 MPa	4751,64 MPa
Shear Stress		1589,19 MPa	2835,89 MPa
Von Misses Stress		2757,46 MPa	5500,6 MPa

4. CONCLUSION

The aim of this paper was to use the FEM application for detailed qualitative and quantitative study of grinding. Analytical methods nowadays cannot enlarge knowledge about this process. Its deep survey and understanding enables the further development of the new and optimization of the existing technologies. Both of them are necessary for preserving of competitiveness.

This study should be taken as a preliminary. Further research in this area is needed. Experimental validation of simulation is also required.

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