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Finite element simulation of the C70 orthogonal cutting process

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Abstract. Finite element simulations are intended to predict the effects of the technological parameters on the cutting process. The process simulation may reveal many aspects of the cutting process before testing it in laboratory: thermal transfer, elastic and plastic strains, hardening levels and force levels. Simulation is also used for predicting some process issues that are hard, and even impossibly noticeable. This paper analyzes the influence of the K factor on the cutting of C70 material, from the point of view of chip formation and thermal transfer - elements considered important in the evolution of tool wear on the rake and flank surfaces. The chip formation is also studied and considered as a deciding factor in choosing the right geometry of the tool. The obtained results allow to make observation under the optimal geometry that was tested.

1 Introduction

The simulation goal is to predict what might happen in a real cutting process. FEM (finite element method) is used for crash tests, fluid flows, heat transfer, and plastic or elastic strain predictions. Cutting simulation allows seeing how chip is formed or the heat is transferred between the chip and workpiece. Due to the numerous advantages as well as the large availability of commercial FE programs, these phenomena were studied for cutting edges with different K factors. From this point of view, Denkena [1] performed a relevant study with variable K factor (Figure 1).

In Denkena's study [1], the K factor is defined as follows in equation (1):

$$K = S_\gamma / S_\alpha \tag{1}$$

The study conducted an orthogonal cutting process, where S_γ and S_α were variable. The study focused on the influence of the K factor on the separation point, where it was observed that in the case of a symmetric cutting edge the size of the stagnation point increases with increasing of S_γ and S_α and for asymmetrical cutting edge only S_α has a significant influence on the stagnation point.

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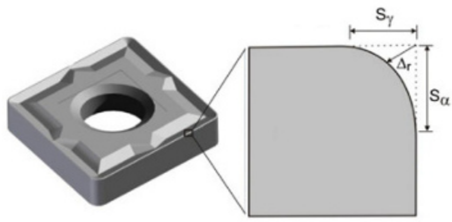

Fig. 1. K factor [1].

S_α - cutting edge segment on the flank face
S_γ - cutting edge segment on the rake face
Δr - profile flattening

In terms of the cutting forces, it was noticed that they increase with the increasing value of S_γ and S_α. This cannot be confirmed in the case of thrust forces F_t, where it appears that these forces grow only when S_α is variable. When S_α is constant and S_γ is variable, the force F_t increases to a specific point, and after that it stabilizes. The temperature during the cutting process has the same value even if S_γ and S_α change. The effect of S_γ and S_α variation on the rake and flank face temperatures was studied by the authors. The main conclusion is that the temperature increases proportionally with S_γ and S_α when K = 1. Segebade [2] has studied the influence of factors K: 0.2; 0.3; 2 and 5, using different cutting parameters during a broaching process. The author studied the influence of K factors on the quantitative grain size and the accumulated plastic strain. Denkena [3] studied the stagnation zone in front of the cutting edge, having asymmetric micro geometries (K~1.7 and K~0.6), observing how the stagnation zone increases when K~1.7, is higher than the stagnation zone for factor K~0.6. This can also be found in paper [4], where the K factors used in the simulation were 0.5 and 2.

This paper deals with the simulation of the C70 orthogonal cutting with the same radius of the cutting edge but different values of the K factor. The orthogonal cutting simulation was chosen due the fact, that in this case it easier to see the influence of the K factor. This material has been chosen, because experiments will be made in the future using this material to compare the simulation with the experimental part. All simulations should lead to an optimal K factor that has to be used in the case of C70 material. This paper aims to emphasize the need of controlling the microgeometry in the machining process.

2 Chip formation and heat transfer during cutting

Three zones of chip deformation can be distinguished during a cutting process (Figure 2): primary deformation zone (1), secondary deformation zone (2), and third deformation zone (3). As the name says, the primary deformation zone is the main deformation zone of the cut material, which is characterized by angle Ø [5]. The secondary deformation zone is the area where the chip moves along the rake face of the cutting tool, in this area being recorded the highest temperature during a cutting process [5]. This is the most sensible problem that has to be studied. As it can be seen in the Figure 2, from the microgeometry of the tool, the cutting edge has no influence on the first deformation zone. The secondary zone is mainly influenced by the macro-geometry (rake angle). The secondary zone is also influenced by the shape of the rake face (concave, convex or plane), the friction coefficient and the usage of cooling fluids. This secondary zone mainly determines the wear of the rake face. Depending on the material and on the work tool, different chip configurations are

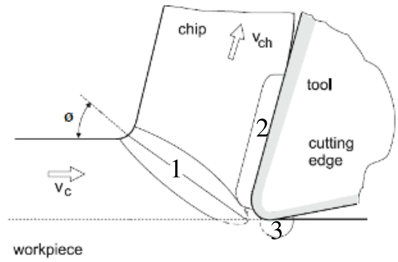

Fig. 2. Cutting mechanism [5].

obtained. The third deformation zone results in material deformation under the flank face of the cutting tool.

From the point of view of the chip, four types of chips can be distinguished: continuous, lamellar, segmented and discontinuous [5] (Figure 3).

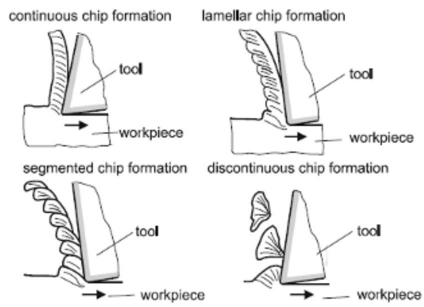

Fig. 3. Types of chips [5].

Heat is released during cutting in different environments such as: chip, tool and workpiece. In order to simplify the FE model, heat transferred to the environment is neglected.

Figure 4 presents the thermal transfer during an orthogonal cutting process. In the primary deformation zone ($Q_{primary\ deformation\ zone}$) (eq. (2)), heat is transferred to the chip ($Q_{deformation\ chip}$), and material ($Q_{deformation\ workpiece}$) that is going to be deformed.

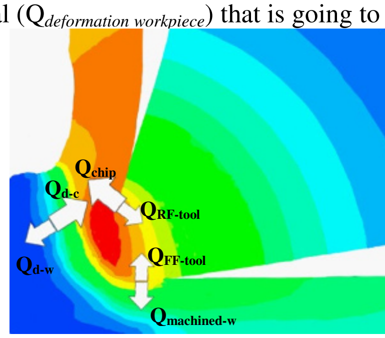

Fig. 4. Heat transfer during cutting.

In the case of the secondary deformation zone ($Q_{secondary\ deformation\ zone}$) (eq. (3)), heat is generated due to the friction between the chip (Q_{chip}) and the rake face of the cutting tool ($Q_{RF\text{-}tool}$). The last zone, where a significant amount of heat is relieved, is the third

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deformation zone ($Q_{third\ deformation\ zone}$) (eq. (4)), where the heat is emitted by the flank face tool ($Q_{FF\text{-}tool}$) respectively in the machined workpiece ($Q_{machined\text{-}workpiece}$).

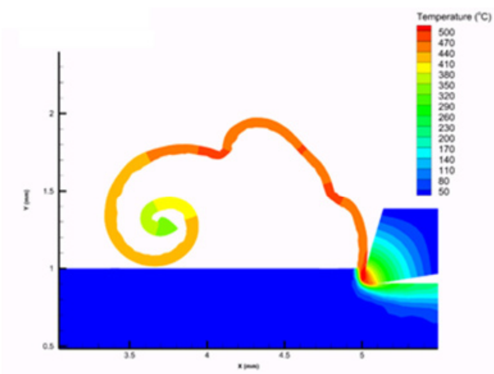
$$Q_{primary\ deformation\ zone} = Q_{deformation\ workpiece} + Q_{deformation\ chip} \tag{2}$$

$$Q_{secondary\ deformation\ zone} = Q_{chip} + Q_{RF\text{-}tool} \tag{3}$$

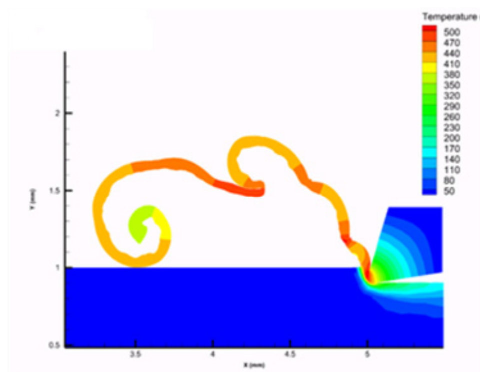
$$Q_{third\ deformation\ zone} = Q_{machined\text{-}workpiece} + Q_{FF\text{-}tool} \tag{4}$$

3 Simulation and discussion

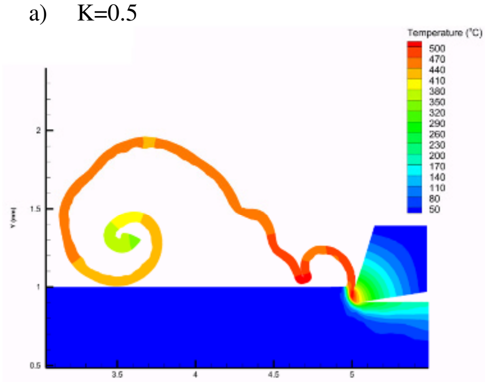
The simulations were performed using the Advant Edge software. The same macro geometry of the cutting tool was used in the orthogonal cutting, as well as the same radius, while the microgeometry K factors were set to the following values: 0.5; 1 and 1.4. All components of the simulation model were meshed with triangular elements of various sizes, with the mention that in the contact zone the elements were smaller with the tendency of



a) K=0.5



b) K=1



c) K=1.4

Fig. 5. Chip formation and temperature in orthogonal cutting.

increasing after losing contact with the tool. In case of the cutting tool made from carbide, with a minimum size of 0.03 mm and a maximum of 0.3 mm of the meshed element. C70 was used as machined material, with the size of the elements in the range of 0.02 mm and 0.1 mm. The cutting parameters of the simulation are as follows: v_c=80 m/min, t=0.1 mm, and an initial temperature of 20°C. The friction coefficient between the cutting tool and material is μ=0.5.

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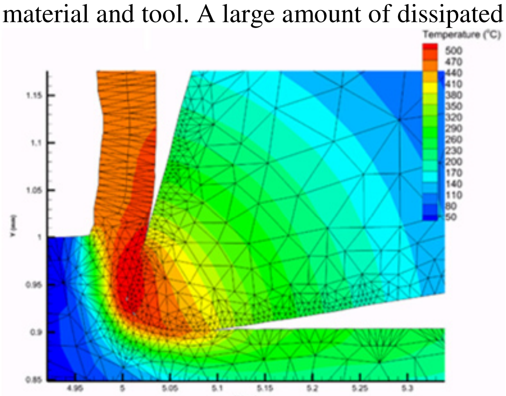
The chip formation was studied in the first stage. As one may notice in Figure 5a), in the case K=0.5, the chip is more compact than in the other two cases (K=1 and K=1.4).

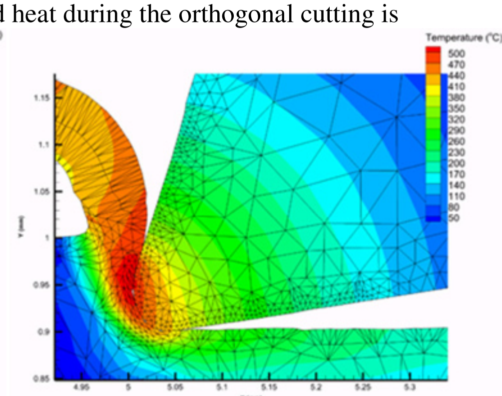
In this case, after the chip makes the first loop, it begins to increase in size, not being restrained like in the beginning and at one point reaching the greatest height (continued chip) of all simulated chip formation. In some cases, this aspect can lead to difficulties in the evacuation of the chip (when machining the interior of cylindrical surfaces).

In the case of orthogonal cutting using K=1 (Figure 5b)), one may notice how the chip is fragmented. The chip presents the most fragmentations, facilitating its evacuation and a lack in the tendency of getting congested. The fragmentation in the case of symmetrical microgeometry is more pronounced than in the case of K=0.5, but similar to K=1.4. The last simulation, where K=1.4 (Figure 5c)) was used, shows how the chip increases a lot more than in the other two cases (K=0.5 and K=1). Unlike the other two simulations, one may notice that the fragmentation of the chip appears a lot later, but after that fragments are shorter.

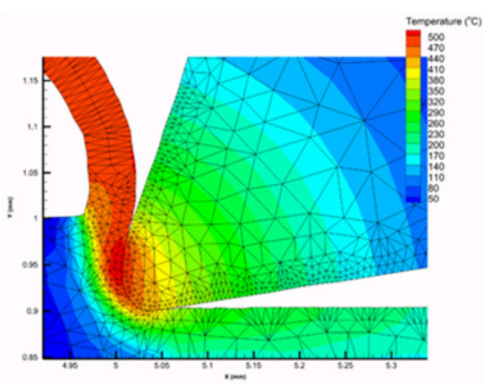
Another important aspect of these simulations is heat dissipation in the chip, machined material and tool. A large amount of dissipated heat during the orthogonal cutting is



a) K=0.5



b) K=1



c) K=1.4

Fig. 6. Temperature distribution in orthogonal cutting.

transferred to the chip. The chip temperature in case of the simulation with a micro-geometry with K=0.5 is higher than in the simulations with K=1, reaching temperatures over 490°C in some areas. By comparison, one may notice in Figure 6 that in the case of cutting with K factor 0.5, the primary and secondary zone generates a higher heat quantity than in the case of utilizing a K factor 1.0. The cutting edge also heats up to temperatures of

500°C, but again one may notice that the heat released in the tool is higher in case of K factors of 1.0 and 1.4. The highest temperature is found on the rake face, confirming the hypothesis issued by Denkena in [5]. This situation can be explained by the fact that the friction of the chip on the rake face is severe due to the contact surface.

According to Figure 6, the deformation zones of the machined material can be differentiated. Case K=0.5 (Figure 6a)) has a smaller primary zone than K=1.0 (Figure 6b)), but the second and the third zone are clearly more extended - fact that leads to a greater amount of heat release. In the case of K=1.4 (Figure 6c)), the third deformation zone is smaller than in the other two cases, resulting in less heat being transferred to the part (chip and tool), despite the fact that the primary deformation zone generates more heat than in the case of K=1.0.

An advantage that can be observed in Figure 5 and Figure 6 is the reduced amount of heat transferred to the part. For the flank face, K factors of 1.0 and 1.4 represent an advantage; despite the fact these two factor levels cannot be really differentiated. Case K=0.5 is inferior from the point of view of thermal stresses induced in the cutting edge. The interrupted chips from case K=1.0 are due to the plastic deformations at lower temperatures than in the other two cases. Due to the high temperatures in the chip (case 0.5 and 1.4) the material becomes ductile and consequently the chip will be of lamellar type or even continued. The lowest temperature at the edge can be found at the cutting tool with K=1.4. During the machining process, the least amount of heat is released in the machined material. The highest temperature following the cutting process can be found in the simulation with K=0.5. In this case, the temperature is higher on the length of the machined workpiece but also in its depth. Here, a high quantity of heat is transmitted in the workpiece and the highest temperature is achieved. For the K=1.4, the temperature of the machined material is higher than in the case K=0.5, but lower than for K=1 (Figure 5).

In terms of the finite element mesh used in the simulations, one may notice how the meshing of the cutting tool does not modify. The elements of the cutting surface following the cutting process have the same shape. The only meshed elements which modify during the cutting process are the ones of the chip and the ones of the material that will be cut in the area of the edge. In all three simulations it can be observed how, in the area of the edge and in the secondary deformation zone, the meshed elements have the same dimensions, having the same variation of the size. In the primary deformation zone, the dimensions of the meshed elements do not vary much in the secondary deformation zone.

4 Conclusions

The research aimed at establishing an optimal microgeometry for machining the C70 material. One may conclude that the K factor is a very important element in the cutting process (but not only in this case). A K factor of 0.5 will lead to generating a large amount of heat and so, to a pronounced wear of the cutting tool both on the flank face and on the rake face**.** It is not recommended to the drilling processes because that does not determine the adequate deformation of the chip for obtaining a lamellar or segmented chip. The microgeometry with a K factor=1.4 determines the formation of chips with lamellar shape and tending towards a segmented shape, but having an advantage over the 0.5 micro-geometry, of generating a large amount of heat transmitted towards the chip and not towards the preform.

The K factor 1.0 is the most advantageous from the thermal point of view. The amount of heat is the lowest in this case. The chip takes the majority of the heat, but the types of the chips that are obtained are lamellar which can be segmented and so are easy to evacuate. The tendency of heat generation in the third area is small, so the flank face is protected against thermal stresses. The secondary area of deformation is the most reduced.

The future research will be focused on obtaining different types of microgeometries on different types of cutting tools in order to validate the theory that has been deduced form FE simulation and implementing it in the industry.

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