DETERMINATION OF THE WORKING INSERT LIFE IN MACHINING 100Cr6 HARDENED STEEL WITH CUTTING FLUIDS

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Abstract: Machining of hardened steels primarily is associated with significant values of contact pressure, contact shear and contact temperature in the contact zone of cutting tool. Currently in machining of specifies materials widely used a carbide cutting inserts with PVD-coating. To change the thermo mechanical loading of the cutting insert different methods of assisted machining are used, such as cutting fluids that is one of the leading position, due to the ease of use and relatively low cost. The main actions of cutting fluids are the cooling and lubricating. The method for determining the cutting conditions and the combination of cooling and lubricating actions of cutting fluids in machining 100Cr6 hardened steel (45 HRC) was proposed, providing maximum working life of carbide insert with TiAlN-coating. The working insert life corresponds to the volume of material removed by cutting insert in tool life period. The insert tool life was determined by a regression equation of the tool life dependence of thermo mechanical loading parameters. To solve these problems the numerical models were used. These models take into account the physical and mechanical properties of machining and tool materials, their contact interaction, cutting conditions and cutting tool geometry, material behaviour at large strains, including the phenomenon of work hardening, dynamic processes and heat-drawing process. Thus, the thermo mechanical loading parameters of the cutting insert (contact pressure, contact shear and contact temperature) was determined on the basis of thermo mechanical modelling of the cutting process by finite element method in the software SIMULIA/Abaqus (Dassault Systèmes, France). An Arbitrary Lagrangian-Eulerian formulation method was used. The cutting processes for the different cutting conditions and combination of cooling and lubricating actions of cutting fluids were simulated. The obtained results of numerical simulation of the cutting insert loading primarily are explained by the response of the work material to the effect of strain hardening, strain rate and temperature as well as the nature of the tribological interaction with the cutting insert. Based on the working insert life dependence of cutting parameters, the cutting conditions were identified that ensure maximum working life of carbide insert with TiAlN-coating. The developed method can also be applied to determine the cutting conditions and the combination of the cooling and lubricating actions of cutting fluids for other materials and cutting tools.

Key words: cutting, thermo mechanical loading, working insert life, cutting fluids, 100Cr6.

1. INTRODUCTION

The Machining of hardened steels primarily is associated with significant values of contact pressure, contact shear and contact temperature in the contact zone of cutting tool. Currently in machining of specifies materials widely used a carbide cutting inserts with PVD-coating. To change the thermo mechanical loading of the cutting insert different methods of assisted machining are used, such as cutting fluids that is one of the leading position, due to the ease of use and relatively low cost. The main actions of cutting fluids are the cooling and lubricating. Manufacturers provide a wide range of cutting fluids, which have different combinations of lubricating and cooling properties. Depending on cutting conditions, this combination can reduce tool wear in different degrees, and, in some cases, to even increase it, [1].

One of the important optimization factors in choosing cutting conditions is a working insert life. The working insert life corresponds to the volume of material removed cutting insert in tool life period.

In this regard, the task of developing a model of thermo mechanical of the machining process, which would predict the impact of cutting conditions and cutting fluid on working insert life on the basis of the contact stresses and temperatures, is important.

The objective of this study is to determine the cutting conditions and the combination of cooling and lubricating actions of cutting fluids in machining 100Cr6 hardened steel (45 HRC), providing maximum working life of carbide insert with TiAlN-coating.

2. METHODOLOGY

These studies were performed for longitudinal turning. The work material is a hardened steel 100Cr6 (45 HRC), the characteristics and the law behaviour at large strains are presented in [2]. The tool material is a SP0819 of ATI Stellram CNMG542A-4E SP0819 CNMG160608E-4E, consisted of TiAlN-coating on fine-grained carbide substrate.

The thermo mechanical model of the turning process has been implemented in the code SIMULIA/Abaqus Explicit 6.10. These models take into account the physical and mechanical properties of work and tool materials, their contact interaction, cutting conditions and cutting tool geometry, material behaviour at large strains, including the phenomenon of work hardening, dynamic processes and heat-drawing process.

For the studies necessary to obtain the following information regarding the loading of the tool during cutting: a contact pressure σ, a contact shear τ, a contact temperature θ. To obtain this information the dynamic explicit analysis was used (type of the elements – coupled temperature-displacement).

To simulate the cutting process by finite element method use the Arbitrary Lagrangian-Eulerian approach, which largely avoids the problems associated with the degradation of the finite element mesh, as in the case of the Lagrangian approach, [3].

Geometry, physical and mechanical properties of the cutting insert (substrate and coating) and work material are embedded in the model.

Among the various laws of material behaviour at large deformations, the most popular is Johnson-Cook law. It takes into consideration temperature gradients and the adiabatic shear phenomenon, caused by large plastic deformations, [4]:

$$\sigma = \left(A + B \cdot \varepsilon^n\right) \cdot \left(1 + C \cdot \ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right) \cdot \left(1 - \left[\frac{T - T_0}{T_f - T_0}\right]^m\right) \quad (1)$$

Parameters of the Johnson-Cook model for the hardened steel 100Cr6 (45 HRC) are presented in Table 1.

Table 1. Parameters of the Johnson-Cook model of the steel 100Cr6, [2]

A, MPa	B, MPa	C	n	m	ε_0	T_f, °C	T_0, °C
280	1215	0.031	0.43	1	0.001	1800	20

The contact law between the surface of the cutting tool and work piece defined by set of mechanical and thermal phenomena. A mechanical phenomenon is described by a model of friction. In our case, we assume an isotropic model of Coulomb, [5]. The friction coefficient of the hardened steel 100Cr6 (45 HRC) and TiAlN-coating is equal to 0.3. Thermal effect is described by the distribution coefficient of the heat flux generated by friction, [3]. Thus, 57% of the heat flux generated at the contact boundary of the work piece and cutting insert is directed to the work piece. Take into consideration also the heat conduction coefficient for a pair of the work piece and tool material. According to [6] it is equal to 10^8 W·m^2·°C. Assume a minimum distance of the coefficient equal to 1μm.

A simulation of lubricating action of cutting fluid performed by embedded to the model a respective average coefficient of friction in the contact zone of cutting tool, cutting fluid and workpiece. A simulation of the cooling effect is realized by embedded a heat transfer coefficient of cutting fluid α, [7]:

$$\alpha = \frac{Nu \cdot \lambda}{D_{eq}} \quad (2)$$

where Nu - Nusselt number; λ - thermal conductivity, [W m-1·°C -1]; Deq - equivalent diameter, [m].

After turning simulation various contact zones of cutting insert and work piece material have been identified: the contact zone of cutting insert with the chip 1, with the large deformation zone 2, with the crushing workpiece zone by the rounded part of the cutting edge 3, with the worked material 4, (Figure 1).

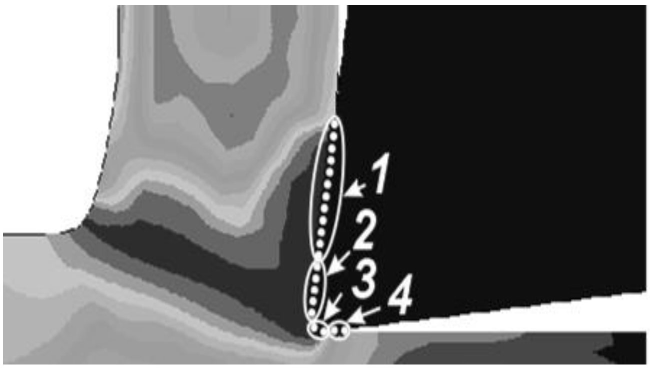


Fig. 1. Contact zones

The local working insert life R (cm^3) is the volume of material removed by cutting insert in tool life of contact zone:

$$R_i = T_i \cdot Q \quad (3)$$

where Ti – tool life of i-th contact zone, [min]; Q – volume of material removed by cutting insert in minute, [cm^3/min].

The insert tool life was determined by the regression equation of tool life and thermo mechanical loading parameters (contact pressure σ, contact shear τ contact temperature θ) expressed by the following relationship, [8]:

$$T(\sigma,\tau,\theta) = e^{25{,}06 + 0{,}01\cdot\ln(\sigma) - 0{,}79\cdot\ln(\tau) - 3\cdot\ln(\theta)} \quad (4)$$

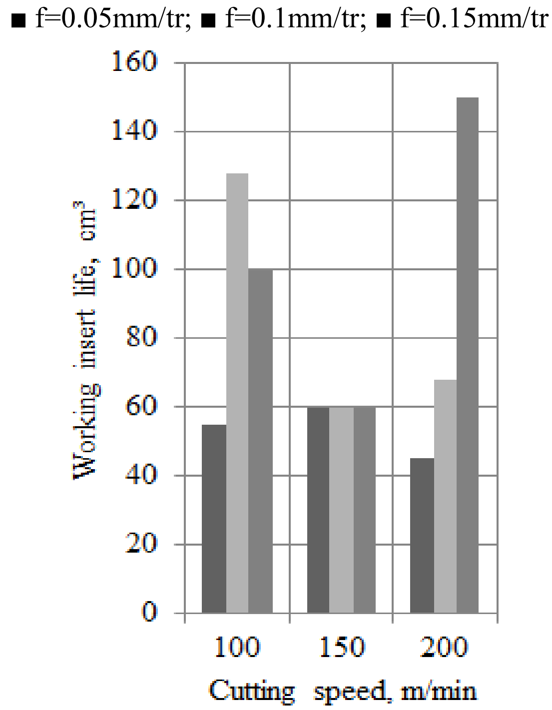
The error of this dependence does not exceed 16%.
The volume of material removed cutting insert by minute:

$$Q = v \cdot f \cdot a \quad (5)$$

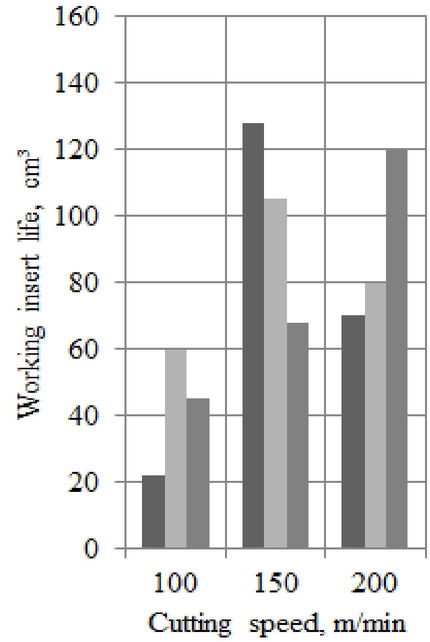
where v – cutting speed, [m/min]; f – feed,[mm/tr]; a – depth, [mm].
The working insert life is determined on base of the local minimum working insert life.
The first series of simulation tests was performed to determine the optimal cutting conditions of turning without cutting fluids, providing maximum working life of carbide insert.
The cutting speed was varied in the interval v=(100-200)m/min (increment 50m/min), the feed f=(0.05-0.15)mm/tr (increment 0.05mm/tr), the depth a=(1-3)mm (increment 1 mm).
The second series of simulation tests was performed for obtain optimal cutting conditions, providing maximum working life of carbide insert, with the use of three cutting fluids basic types:
-with low cooling and high lubricating actions CF1: $\alpha = 20$kW/(m2·K), μ=0.15;
-with medium lubricating and cooling actions CF2: $\alpha = 40$kW/(m2·K), μ=0.2;
-with high cooling and low lubricating actions CF3: $\alpha = 60$kW/(m2·K), μ=0.25.

3. RESULTS AND DISCUSSIONS

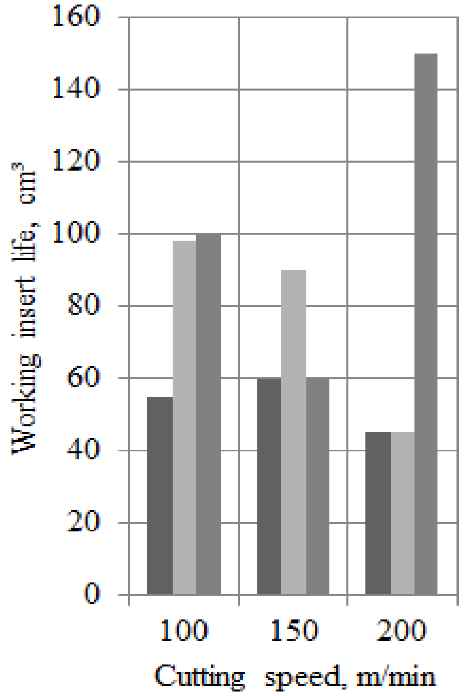
The cutting processes for the different cutting conditions and combination of cooling and lubricating actions of cutting fluids were simulated. The obtained results of numerical simulation of the cutting insert loading primarily are explained by the response of the work material to the effect of strain hardening, strain rate and temperature as well as the nature of the tribological interaction with the cutting insert.
The first series of simulation was performed to determine the optimal cutting conditions of turning without cutting fluids, providing maximum working life of carbide insert (Figure 2).
The developed method allowed us to determine the cutting conditions of turning without cutting fluids (v=200m/min, f=0.15mm/tr, a=2mm and v=200m/min, f=0.15mm/tr, a=3mm) providing a maximum value of working insert life 150cm^3, which was in 7 times more than the cutting conditions, which caused the minimum value of working insert life (v=100m/min, f=0.05 mm/tr, a=1mm).
The highest values of the local working insert life observed with the cutting insert cutting conditions: v=150m/min, f=0.15mm/tr, a=1mm; v=200m/min, f=0.05mm/tr, a=1mm; v=200 m/min, f=0.05 mm/tr, a=3mm; v=200 m/min, f=0.15mm/tr, a=2 mm; v=200 m/min, f=0.15 mm/tr, a=3mm.
However, for these cutting conditions, the value of the local working insert life in contact zones 1 and 4 are lower than for the contact zones 2 and 3.
Therefore, in this case it is advisable applying of cutting fluids to improve local working insert life in said contact zones (Figure 3).



a) depth a=1mm



b) depth a=2mm



c) depth a=3mm

Fig. 2. Impact of cutting speed and feed on the working insert life with the depth a=1mm (a), with the depth a=2mm (b), with the depth a=3mm (c)

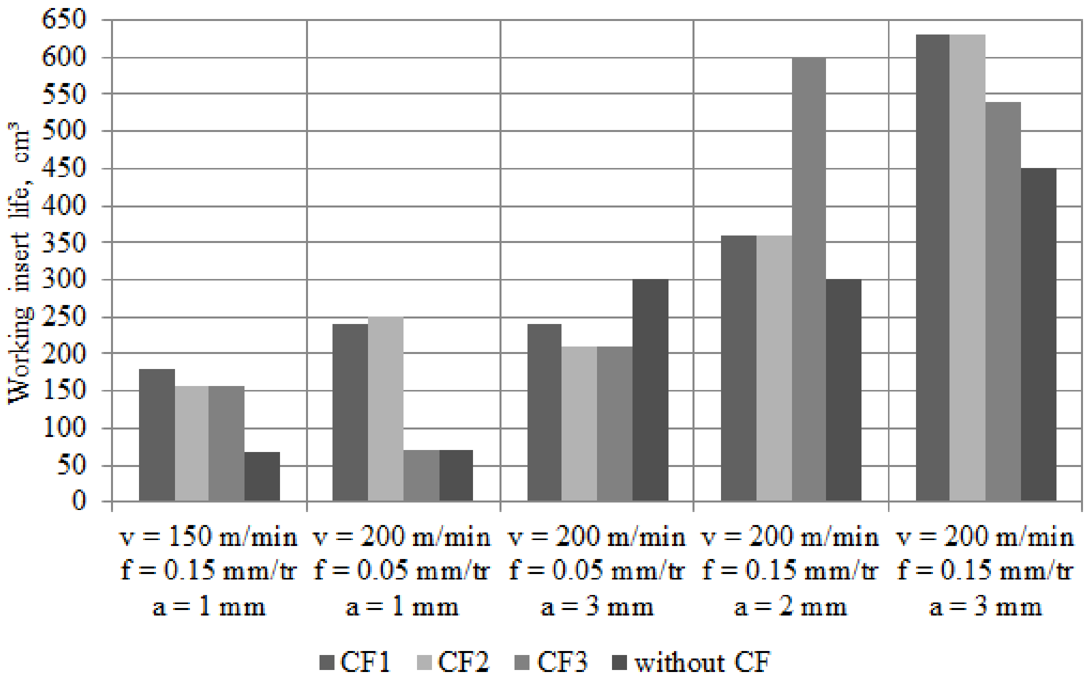


Fig. 3. Impact of cutting conditions and type of cutting fluids on the working insert life

However CF1 or CF2 in the contact zone 4 can significantly improve working insert life at the expense of ensuring the minimum stress and temperature. Such a reduction of stress can be explained by their displacement in the contact zone 3, where the working insert life value is not allowed. CF3 due to high cooling action adversely affect the process of turning hardened steel 100Cr6 (45 HRC): reducing temperature causes an increase in shear stresses. The use of cutting fluids for these cutting conditions is impractical, although the supply of all types of cutting fluids on the front surface allows for a more even distribution of wear between the contact zones 1 and 2.

The cutting conditions v=200m/min, f=0.05mm/tr, a=1mm with using CF1 or CF2 greatly increases the value of local working insert life, except the contact zone 2 with using CF1 and the contact zone 3 with using CF2, where it is slightly reduced. CF3 is not recommended for these cutting conditions.

The cutting conditions v=200m/min, f=0.05mm/tr, a=1mm with a supply of CF1 or CF2 on the front surface substantially reduces the value of local working insert life, when applied to the flank surface - due to the stress displacement in contact zone 3, increases the local working insert life of contact zone 4. CF3 is not recommended for these cutting conditions, as CF1 and CF2.

The cutting conditions v=200m/min, f=0.15mm/tr, a=2mm with a supply of any kind of cutting fluid on the front surface reduces value of local working insert life and with a supply on the flank surface - increases.

The cutting conditions v=200m/min, f=0.15mm/tr, a=3mm CF1 increase the local working insert life of contact zones 1 and 3, but reduces the contact zones 2 and 4. Thus, a supply on the front or flank surface will cause a reduction of local working insert life of the one of contact zones, but a supply on the front surface allows for a more even distribution of wear between the contact zones 1 and 2. CF2 and CF3 increase the value of local working insert life in the contact zones 1, 2 and 3, but this reduces in the contact zone 4. Consequently, these types of cutting fluids are recommended to apply only on the front surface.

The maximum value of working insert life 630cm^3 is provided with cutting conditions v=200m/min, f=0.15mm/tr, a=3mm and supplying of cutting fluids with low cooling and high lubricating actions or with medium lubricating and cooling actions on the front surface. The minimum value of working insert life 70 cm^3 is provided with cutting conditions v=200m/min, f=0.05mm/tr, a=1mm and supplying of cutting fluids with high cooling and low lubricating actions on the front surface. Thus, the developed method allowed in 9 times increase working inserts life.

4. CONCLUSIONS

This study allowed to determine the cutting conditions (v=200m/min, f=0.15mm/tr, a=3mm) and the combination of cooling and lubricating actions of cutting fluids (supplying of cutting fluids with low cooling and high lubricating actions or with medium lubricating and cooling actions on the front surface) in turning hardened steel 100Cr6 (45 HRC), providing maximum working life of carbide insert with TiAlN-coating 630cm^3. The developed method can also be applied to determine the cutting conditions and the combination of the cooling and lubricating actions of cutting fluids for other work materials and cutting tools.

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