© Strojniški vestnik 49(2003)2,111-118
ISSN 0039-2480
UDK 669.71:620.179.11
Pregledni znanstveni članek (1.02)
© Journal of Mechanical Engineering 49(2003)2,111-118
ISSN 0039-2480
UDC 669.71:620.179.11
Review scientific paper (1.02)

Izbrani vidiki celovitosti površine aluminijeve zlitine pri običajni in obdelavi z velikimi hitrostmi: Spremembe mikrotrdote in hrapavosti površine

Selected Aspects of the Surface Integrity of Aluminium Alloy in High-Speed Machining: Microhardness Variations and Surface Roughness

David Vaněček - Jan Mádl - Mirko Soković

Prispevek se ukvarja s kakovostjo in celovitostjo površine aluminijeve zlitine, nastale pri običajni in obdelavi z velikimi hitrostmi(VHO) . V študiji so uporabljena orodja iz karbidne trdine skupine K. Predstavljeni so rezultati analize mikrotrdote in hrapavosti površine. Meritve mikrotrdote so izvedene tik pod obdelano površino. Analize obdelane površine so predstavljene v območju parametrov hrapavosti površine. Razmerja med spremembami mikrotrdote in hrapavostjo površine so dobljene iz analiz.

(Ključne besede: zlitine Al, obdelave visokohitrostne, integriteta površin, hrapavost površin, mikrotrdota)

This paper deals with the quality and integrity of the surface produced during aluminium-alloy high-speed machining (HSC). Carbide type-K tools were used in this study. The results of the microhardness and surface-roughness analyses are presented. The microhardness measurements were conducted beneath the machined surface. The analyses of the surface produced are presented in a range of surface-roughness parameters. Relations between microhardness variations and surface roughness were obtained from the analyses.

(Keywords: Aluminium alloys, high speed machining, surface integrity, surface roughness, microhardness)

0 UVOD

Parametri, ki se nanašajo na celovitost obdelane površine, so odločilni pri delovanju površine različnih delov. Celovitost površine je zbirka značilnosti, ki opisuje funkcionalne lastnosti površine. To pomeni, da celovitost površine ne popisuje samo topološki vidik površin ter njihove fizikalne in kemične lastnosti, temveč tudi mehanske in metalurške lastnosti in značilnosti. Zapletena teoretična in eksperimentalna raziskava še ni bila do sedaj opravljena za obdelavo z veliko hitrostjo. Seveda lahko eksperimentalno raziskavo podpremo s simulacijo, z uporabo ustrezne programske opreme za simulacijo. Eksperimentalna raziskava, ki temelji na izbranih vidikih obdelave z veliko hitrostjo, je bila opravljena na Češki tehnični univerzi (ČTU) v Pragi. Več poročil o mikrotrdoti in hrapavosti površine, nastalih na površini obdelovanca med obdelovanjem z veliko hitrostjo, je bilo v zadnjem obdobju objavljenih v literaturi ([1] do [10]).

0 INTRODUCTION

Parameters that are related to the integrity of a machined surface are decisive when it comes to the functioning of surface components. The integrity of any surface is a collection of the characteristics that describe the functioning property of the surface. This means that surface integrity describes not only the topological aspects of the surfaces and their physical and chemical properties, but also their mechanical and metallurgical properties and characteristics. Complex theoretical and experimental research has not yet been carried out for high-speed machining. However, experimental research can be supported by simulations using suitable software for these simulations. Complex experimental research on selected aspects of HSC is the object of the research being carried out at the Czech Technical University (CTU) in Prague. Several reports on the microhardness and surface roughness induced on workpiece surfaces during high-speed machining have appeared in the literature ([1] to [10]).

1 EKSPERIMENTALNO DELO

Obdelava z veliko hitrostjo aluminijeve zlitine, brez hlajenja, je bila opravljena z uporabo rezalnih orodij iz karbidne trdine skupine K, na obdelovalnem stroju Taimac – ZPS Zlín MCFV 5050LN. Kot obdelovani material je bila uporabljena aluminijeva zlitina Al 7075. Lastnosti obdelovanega materiala sta bili: natezna trdnost 480 MPa, meja elastičnosti 390 MPa. Postopek predelave zajema valjanje z raztopnim žarjenjem, toplotno obdelavo, gašenje (1,5 do 3 % nadzorovani raztezek), stopenjsko staranje, brez utrjevanja po raztezanju.

Rezalni parametri: Rezalna hitrost je bila od 200 do 1600 m/min, podajanje na zob orodja f = 0,1 mm, globina rezanja a_p = 1 mm.

Pri vseh preizkusih je bila uporabljena nova frezalna glava FRU90 11335 in izmenljive ploščice iz karbidne trdine skupine K ADMX 12T 306ER, proizvajalca Fette, ZRN. Premer frezalne glave je bil 63 mm.

Za merjenje parametrov hrapavosti površine je bila uporabljena naprava Taylor-Hobson, za merjenje mikrotrdote pa merilnik mikrotrdote z video merilnim sistemom.

1 EXPERIMENTAL WORK

Dry aluminium-alloy high-speed machining was performed using carbide type-K cutting tools on a Taimac – ZPS Zlín MCFV 5050LN machine tool. The aluminium alloy Al 7075 was used as the workpiece material. The properties of the workpiece material were: tensile strength 480 MPa, and proof stress 390 MPa. The method of production was rolled with solution, heat-treated, quenched. 1.5 to 3% controlled strenched and step aged, not straightened after stretching.

The cutting specifications were: cutting speed, from 200 to 1600 m/min; the feed per tooth, f = 0.1; the depth of cut, a_p = 1mm.

For all the experimental work we used a new tool and inserts manufactured by Fette: Milling cutter FRU90 11335 with ADMX 12T 306ER chips. The chips were made of Type-K carbide. The cutter diameter was 63 mm.

A Taylor-Hobson device was used for measuring the surface-roughness parameters, and a microhardness tester with a video measuring system used for the microhardness measurements.

2 REZULTATI EKSPERIMENTALNEGA DELA IN RAZPRAVA

2.1 Analiza hrapavosti površine

Dve vrsti parametrov je bilo izmerjenih. Najprej parametri hrapavosti površine Ra, Rq, Ry, Rtm, Rv, Rp, Sm, Δq, Rsk, Rku, S, R_{3Z}, Rpm, $R_{3y,}$ nato pa še parametri valovitosti Wa, Wq, Wt, Wv, Wp, Δq. Da bi izpolnili statistično verodostojnost, smo vse parametre izmerili po petkrat na vseh vzorcih. Analiza rezultatov, podana na sliki 1 (a, b), kaže spremembe parametrov hrapavosti površine in valovitosti za različne rezalne hitrosti.

Slika 1 (a, b) kaže obstoj dveh najmanjših vrednosti (pri rezalnih hitrostih 600 in 1200 m/min) pri večini izbranih parametrov. Ti dve vrednosti, ki jih opazimo pri približno enakih hitrostih, nista razložljivi z vibracijami stroja. Vibracije glavnega vretena so bile prav tako analizirane. Izbrani rezultati so predstavljeni na sliki 2 pri rezalni hitrosti 500 m/min oz. 1000 m/min.

2.2 Analiza mikrotrdote obdelane površine

Lastnosti površine obdelovanca so močno odvisne od krivulje mikroutrjevanja. Oblika krivulje mikroutrjevanja ima lahko pozitiven ali negativen vpliv na kakovost površine. Globina in lastnosti mehansko utrjene plasti so odvisne od dejavnikov, to so: uporabljena metoda predelave, trenje pri drsenju, ki mu je bila površina izpostavljena, pa tudi material obdelovanca.

2 EXPERIMENTAL RESULTS AND DISCUSSION

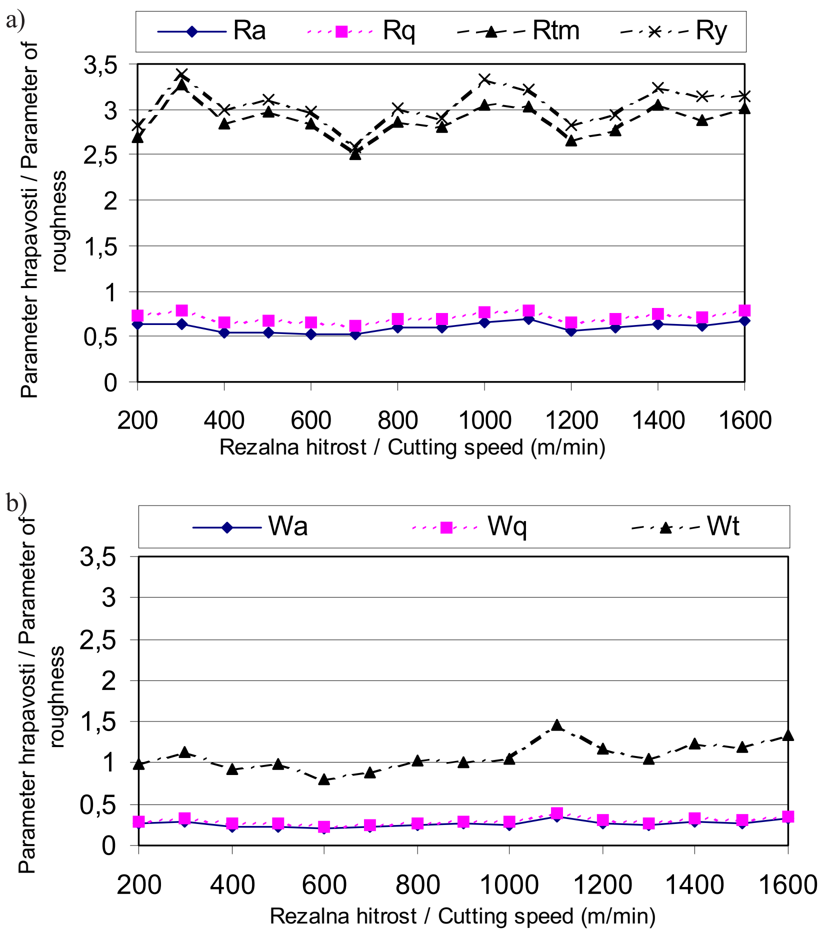
2.1 Surface-roughness analysis

Two kinds of parameters were measured. First, the surface-roughness parameters Ra, Rq, Ry, Rtm, Rv, Rp, Sm, Δq, Rsk, Rku, S, R_{3Z}, Rpm, $R_{3y.}$ Then, the waviness parameters Wa, Wq, Wt, Wv, Wp, Δq. For the purposes of statistical verification, the parameters were measured five times for all the samples. An analysis of the results presented in Fig. 1 (a, b) shows the changes in the surface-roughness parameters (Fig. 1 - a) and the parameters of waviness (Fig. 1 - b) for different cutting speeds.

Fig. 1 (a, b) show that two minima exist (600, 1200 m/min cutting speed) for most of the selected parameters. These two minima, which are observed at approximately the same speeds, cannot be explained by machine vibrations. The machine spindle vibrations were also analysed. Selected results are presented in Fig. 2 – a, 500 m/min, and Fig. 2 – b, 1000 m/min cutting speed.

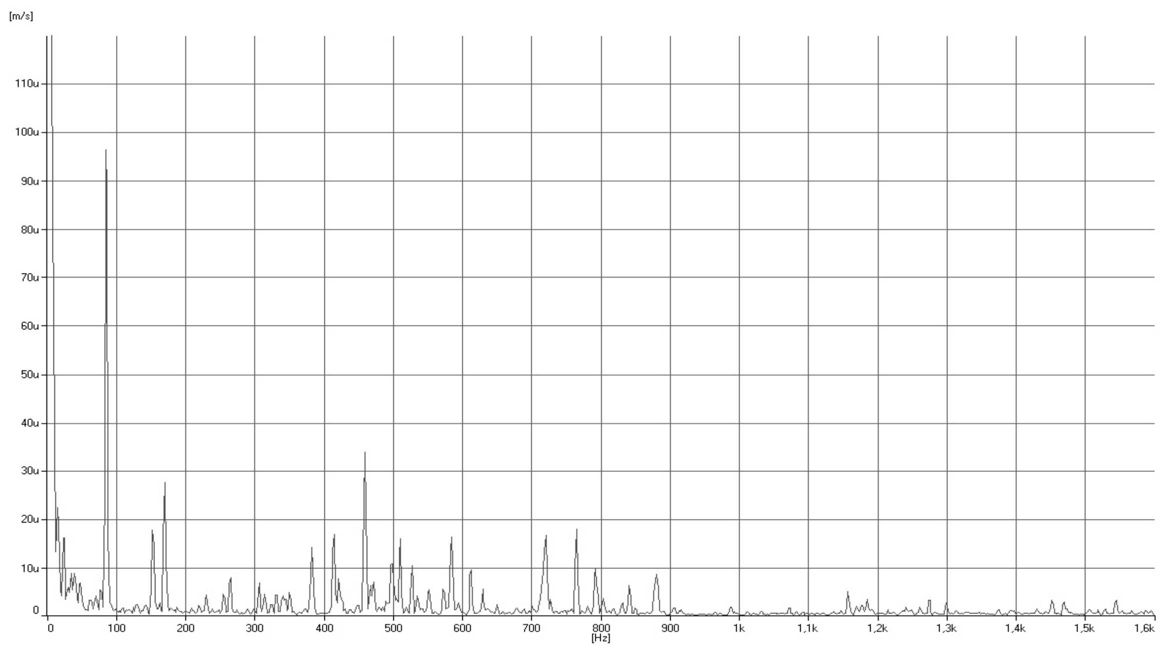
2.2 Microhardness analysis of the produced surface

The properties of the surface of the workpiece depend considerably on the microhardening curve. The shape of the microhardening curve can have a positive or negative influence on surface quality. The depth and properties of the work-hardened layer depend on factors such as the processing method used, the frictional sliding to which the surface was subjected and also the workpiece material.



Sl. 1. *Hrapavost površine (a) in valovitost (b) za površine, obdelane pri rezalnih hitrostih od 200 do 1600 m/min*

Fig. 1. *Surface-roughness (a) and waviness (b) variations for a surface produced at cutting speeds from 200 to 1600 m/min*



Sl. 2. *Autospekter vibracij glavnega vretena*

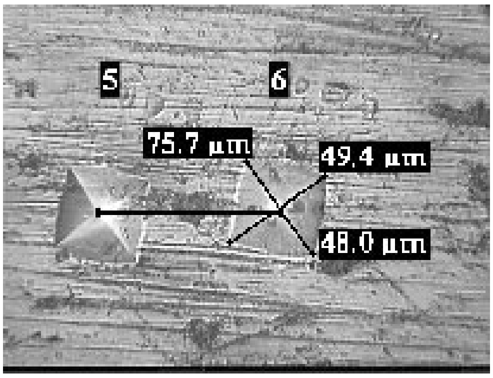
Fig. 2. *Autospectrum - relation between amplitude of velocity (m/s) and frequency (Hz)*

Obseg sprememb mikrostrukture pod površino ter spremembe mikrotrdote v površinski plasti so bile tudi merjene. Slika 3 prikazuje praktičen primer merjenja mikrotrdote, slika 4 pa podrobno ponazarja spremembe mikrotrdote v globino pod obdelano površino, nastalo pri različnih rezalnih hitrostih: (a) 200, 400 in 500 m/min; (b) 600, 800 in 900 m/min; (c) 1000, 1100 in 1300 m/min; (d) 1400, 1500 in 1600 m/min.

Za stopnjo mehanskega utrjevanja K_z (ki je lahko izračunana iz povprečnih vrednosti (sl. 5 a), oziroma iz največjih vrednosti (sl. 5 b)), lahko vzamemo, da je:

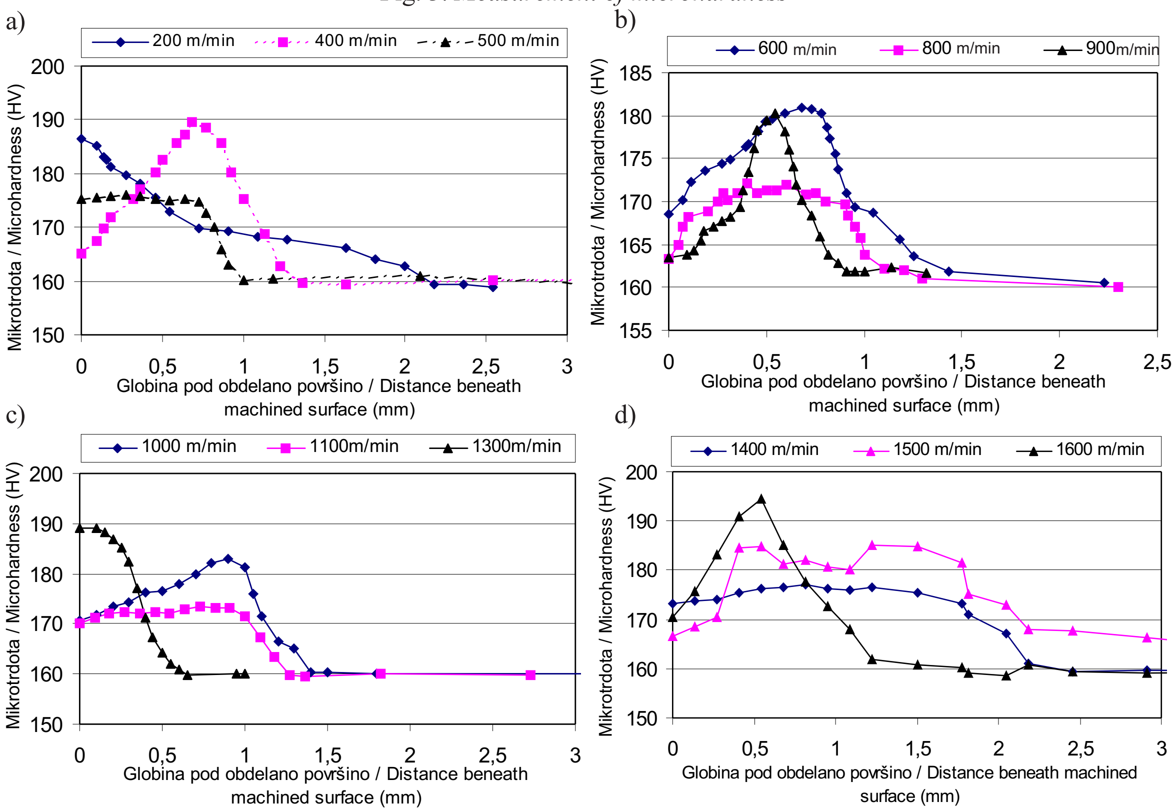
The extent of the changes in the subsurface microstructure and the subsurface microhardness were measured. Figure 3 shows the measurements of microhardness. Figure 4 details the variations in the microhardness with depth beneath the machined surface produced by different cutting speeds (Figure 4 – a: 200, 400 and 500 m/min; 4 – b: 600, 800 and 900 m/min; 4 – c: 1000, 1100 and 1300 m/min; 4 – d: 1400, 1500 and 1600 m/min).

Fig. 5 Rate of the work hardening K_z, which can be assumed to be:



Sl. 3. *Merjenje mikrotrdote*

Fig. 3. *Measurement of microhardness*



Sl. 4. *Spremembe mikrotrdote pod obdelano površino, nastalo pri različnih rezalnih hitrostih:*
a) v_c *= 200, 400, in 500 m/min; b)* v_c *= 600, 800, in 900 m/min;*
c) v_c *= 1000, 1100, in 1300 m/min; d)* v_c *= 1400, 1500, in 1600 m/min*

Fig. 4. *Microhardness variations beneath the surface produced at different cutting speeds:*
a) v_c*=200, 400, 500 m/min; b)* v_c*=600, 800, 900 m/min;*
c) v_c*=1000, 1100, 1300 m/min; d)* v_c*=1400, 1500, 1600 m/min*

$$K_Z = \frac{HV_Z - HV_O}{HV_O} \times 100 \ (\%)$$

pri čemer pomenita:

HV_Z - mikrotrdoto mehansko utrjenega materiala,

HV_O – mikrotrdoto začetnega (neutrjenega) materiala.

Slika 6 prikazuje celotno globino utrjevanja za različne rezalne hitrosti od 200 do 1600 m/min. Slika 7 podaja podrobno analizo globine največjega utrjevanja za različne rezalne hitrosti od 200 do 1600 m/min. Slika 8 podrobno prikazuje spremembe vrednosti največjega utrjevanja pri posameznih rezalnih hitrostih od 200 do 1600 m/min. Celovita smer utrjevanja v izbranih diagramih je prikazana s pikčasto in črtkano črto v teh diagramih.

Koeficient celotnega utrjevanja, prikazanega na sliki 9, lahko določimo kot:

where are:

HV_Z – microhardness of the work-hardened material

HV_O – microhardness of the non-work-hardened material

Fig. 6 analyses of the total depth of hardening for different cutting speeds 200 to 1600 m/min. Fig. 7 provides a detailed analysis of the depth of the maximum hardening for different cutting speeds 200 to 1600 m/min. Fig. 8 details the variations of the maximum hardening values for different cutting speeds 200 to 1600 m/min. The overall tendency for the selected graphs is shown by the thin line in the graphs.

The coefficient of total hardening presented in Fig. 9 can be assumed to be:

$$k = \frac{1}{100} \times \sum_{i=1}^{n} (HV_{Xi} \times \Delta)$$

pri čemer pomenijo:

HV_{Xi} – povprečno vrednost mikrotrdote,

Δ – širino stolpca,

n – število stolpcev, upoštevanih pri izračunu.

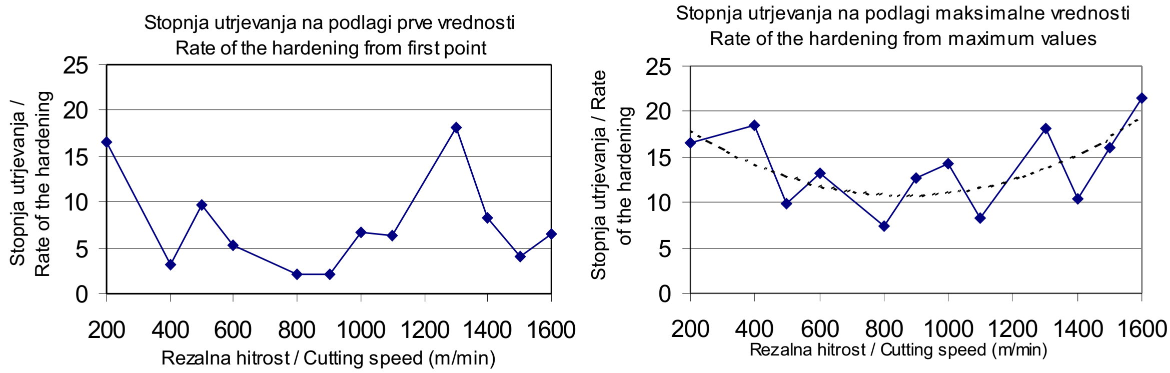
where are:

HV_{Xi} – mean values of microhardness,

Δ – width of columm,

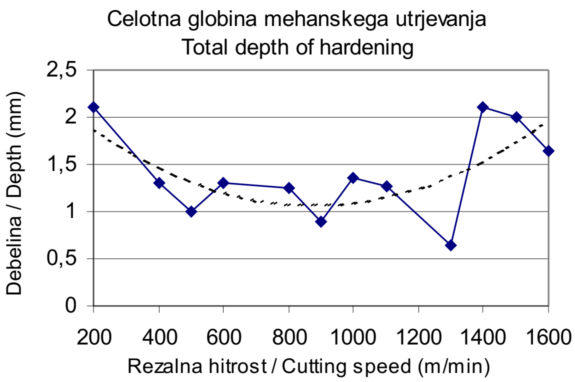
n – number of columms taken into account.

a) b)



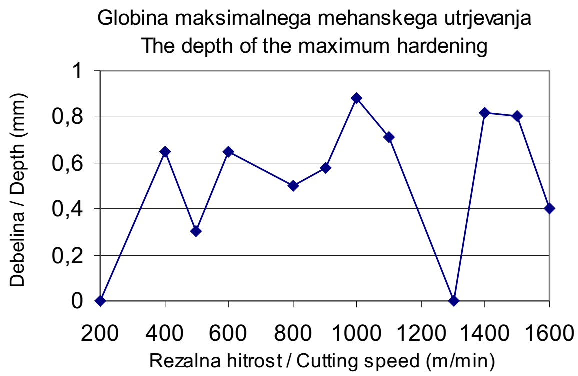
Sl. 5. *Stopnja mehanskega utrjevanja na podlagi prve vrednosti (a) in na podlagi maksimalne vrednosti (b)*

Fig. 5. *Rate of work hardening (a) and rate of maximum values (b)*



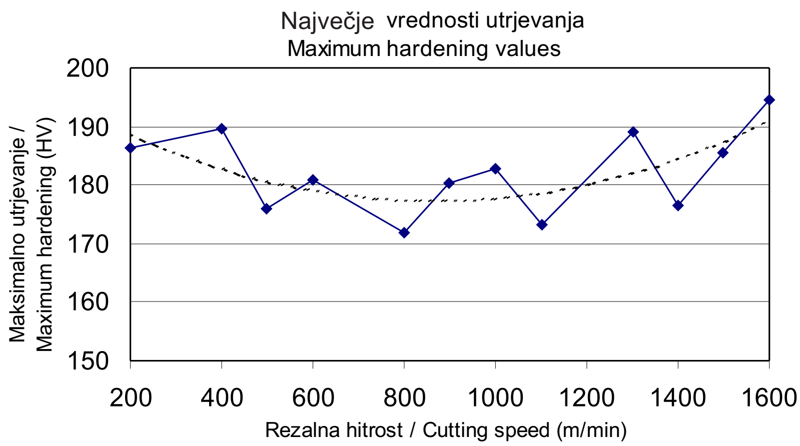
Sl. 6. *Analiza največje globine mehanskega utrjevanja za različne rezalne hitrosti*

Fig. 6. *Analysis the variations of maximum hardening values for different cutting speeds*

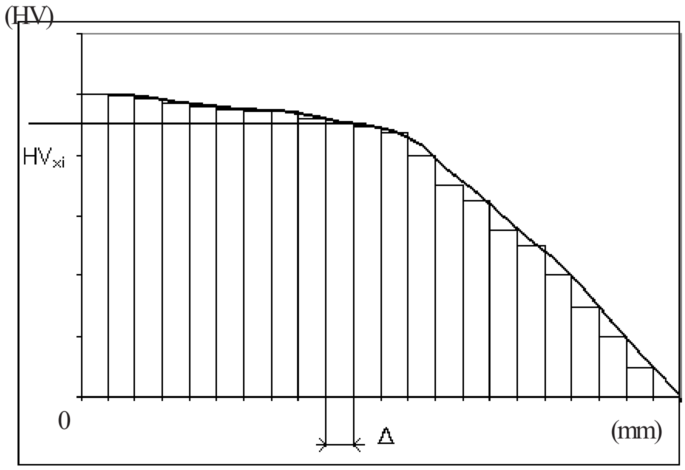


Sl. 7. *Analiza globine največjega mehanskega utrjevanja za različne rezalne hitrosti*

Fig. 7. *Analysis of the depth of maximum work hardening for different cutting speed*



Sl. 8. *Podroben prikaz spremembe vrednosti največjega utrjevanja pri posameznih rezalnih hitrostih*
Fig. 8. *Details the variations of maximum hardening values for different cutting speeds*



Sl. 9. *Načelo izračuna koeficienta celotnega utrjevanja*
Fig. 8. *Principle of calculation of coefficient of total hardening*

Rezultati na sliki 10 kažejo, da sta bili največji vrednosti mehanskega utrjevanja doseženi pri rezalnih hitrostih med 1400 do 1600 m/min ter pri 200 m/min. Poglavitni razlog za najvišje vrednosti mehanskega utrjevanja pri rezalni hitrosti med 1400 in 1600 m/min so velike vrednosti celotne globine mehanskega utrjevanja. Po drugi strani pa so, za rezalne hitrosti med 200 do 400 m/min, glavni razlog za močno utrjevanje prav velike vrednosti za HV_{xi}.

3 SKLEP

Učinek rezalne hitrosti na hrapavost površine in mikrotrdoto pod obdelano površino, nastalo pri obdelavi aluminijeve zlitine brez hlajenja, z izmenljivimi ploščicami iz karbidne trdine skupine K, je bil eksperimentalno določen. Zaostale napetosti še niso bile v celoti analizirane. Učinek toplotne obremenitve na mehčanje zgornjih plasti je raziskovan le za nekatere rezalne hitrosti; za simulacijo je uporabljena programska oprema AdvantEdge (metoda končnih elementov). Rezultati simulacije bodo objavljeni drugje.

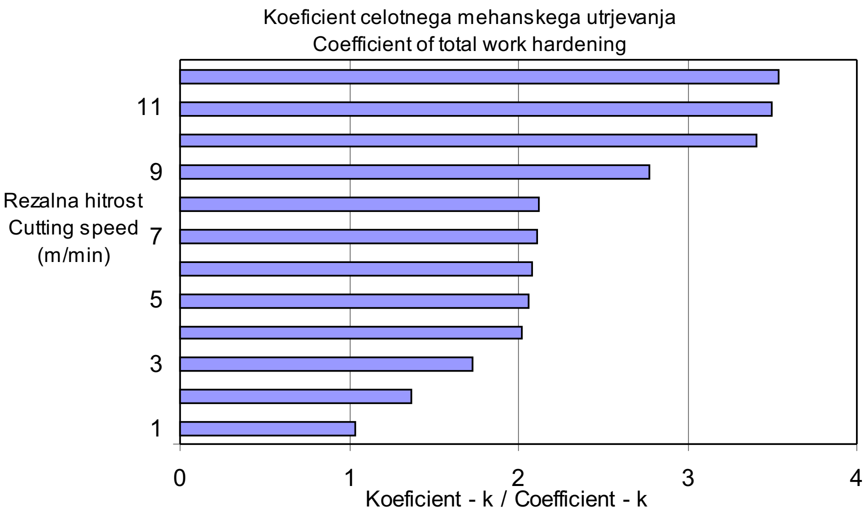
Na podlagi eksperimentalnih rezultatov lahko podamo naslednja sklepa:

The results presented in Fig.10 show that the highest values of work hardening were obtained for the 1400 to 1600 m/min and 200 to 400 m/min cutting speeds. The main reason for the highest values of work hardening at the 1400 to 1600 m/min cutting speeds are the total depth of the work-hardening values. On the other hand, for cutting speeds of 200 to 400 m/min the main reason for the highest values of the work hardening are the high values of work hardening (HV_{xi}).

3 CONCLUSION

The effect of cutting speed on the surface roughness and microhardness beneath the surface produced during dry aluminium-alloy machining using carbide type-K was investigated experimentally. The residual stresses have not yet been completely analysed. The effect of the thermal load on the softening of the upper layers investigated for some cutting speeds is being investigated by AdvantEdge finite-element method simulation software. The results will be published elsewhere.

The following conclusions can be drawn from the experimental results:



Sl. 10. *Koeficient celotnega mehanskega utrjevanja*
Fig. 9. *Coefficient of total work hardening*

1. Rezalna hitrost v raziskovanem območju vpliva na hrapavost površine. Pri rezalnih hitrostih 600 in 1200 m/min je dosežena hrapavost površine nekoliko manjša kakor pri preostalih rezalnih hitrostih. Rezultati bodo izrazito zmanjšanje časa obdelave, kar pa je zelo pomembno za ekonomičnost industrijskih postopkov.
2. Rezalna hitrost ima izrazit vpliv na spremembe mikrotrdote. Izbrane parametre kakovosti površine obdelovanca (trdnost, trdota – njihove vrednosti in potek) lahko izboljšamo z izbiro primerne rezalne hitrosti.

Rezultati projekta LN00B128 so bili finančno podprti od Ministrstva za šolstvo Češke Republike.

1. The cutting speed has an influence on the surface roughness. For 600 and 1200 m/min , the cutting speed used is lower than for the other cutting speeds used. However, the cutting speed has less influence on the surface roughness than the feed rate or the cutting-edge radius.
2. The cutting speed has a significant influence on the variations in microhardness. Selected parameters of workpiece surface quality can be improved by choosing a suitable cutting speed (strength, hardness, their values and their range)

The results of project LN00B128 were financially supported by the Ministry of Education of the Czech Republic.

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Prejeto: Received: 20.12.2002
Sprejeto: Accepted: 29.5.2003
Odprt za diskusijo: 1 leto
Open for discussion: 1 year