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INFLUENCE OF EDGE RADIUS OF SINTERED-CARBIDE TIP ON ROUGHNESS OF MACHINED SURFACE

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Abstract

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Increasing of cutting speed and thus increasing labour productivity is observed as a current trend in engineering production. This effort results to development of new cutting materials which are more capable to resist increased requirements on machined surface as well as operating life of the instrument. Nowadays, the most widely used materials used for cutting instruments are sintered carbides which are alloyed by other metals.

The goal of this paper is to analyse change in quality of machined surface depending on the change of cutting conditions. For cutting operation, there were used a milling cutter high-speed steel 90 (HSS) and removable sintered-carbide tips with different radius. Steel 12 050 hardened for 17 HRC was used as a machined material.

Firstly, hardness of machined as well as machining materials was analysed. Further, metallographic analysis and measurement of microhardness of the individual structure phases was processed. Cutting conditions of both instruments were selected depending on the machined material. Surface roughness indicates the quality of machined surface.

cutting conditions, tips, sintered carbide, milling, surface roughness

There is a wide range of cutting instruments – from rapid steels to extra hard materials. Machining of different materials requires using different cutting instrument materials (Humár, 2008). Cutting conditions during machining significantly influence the quality of machined surface. Due to the pressure of increasing labour productivity, some parts of the machining instruments are extensively worn out, which results not only in worsening a quality of machined surface but also in shortening operating life of the whole machine tool (Marek, 2012). If vibrations from machining tool are transferred to a cutting edge of an instrument, delamination of a tip may occur; thereby the whole production process may be broken; resulting also in worsened surface quality which is dependent on even chips lead-away (Žitnavský *et al.*, 2012).

There occurs an abrasive wear of a machining instrument during the machining process, which results in an angle change of removable tip cutting edges. As a result, cutting tool thrust and cutting resistance increase (Stachowiak, 2005), which can be eliminated by using cutting liquids and oils. However, when hard materials are machined using cubic boron nitride (further CBN) any cooling is undesirable as a temperature shock would cause destruction of a cutting instrument. In general, the usage of cutting liquids in machining is being eliminated (Žitnavský *et al.*, 2005).

Cutting angles on an instrument must guarantee achieving quality surface in the machining process. The research in this field focuses on radius of cutting tips and its influence on the quality of machined surface of machine works after heat treatment (Ščerbejová, 1993). The aim of this paper is to evaluate commercially sold cutting tips with a different tip radius.

MATERIAL AND METHODS

For milling, removable cutting tips were used, see Tab. I. These cutting tips were used in the combination of milling cutter 63A06R-S90AD16E-C.

Types of cutting tips:

- ADMX160608SR-M
- ADMX160616SR-M
- ADMX160632SR-M.

For further tests according to the norm ČSN 22 2158, a shell end milling cutter NAREX 63x40 HSS 90, which is fine-pitched tool, was used. Technical characteristics are written in Tab. II.

Both of the above mentioned tools are widely used in technical practice. In the cutting operation it is necessary to cutting conditions.

As shell end milling cutter is made of high-speed steel 19 810, the cutting speeds must be lower comparing to the materials of sintered carbide. Breaking cutting conditions may cause defect or destruction of the whole tool (Žitňanský *et al.*, 2012).

In order to measure roughness of the machined surface, steel 12 050 was used. This material is suitable for treatment; it has a good sturdiness and sufficient hardness (Řasa, 2007). Chemical composition and heat treatment are recorded in Tab. III and IV.

Samples sized 100 × 50 × 20 mm were cut from these heat treated steels. For milling the depth of cut of 1 mm was selected.

RESULTS AND DISCUSSION

Hardness measurement according to ČSN EN ISO 6507

Resulting hardness of a tool has a big influence on its operating life and its overall wear (Dillinger, 2007). In the conditions of cutting operation, it also depends on ductility and the ability of the

I: *Removable cutting tips*

Type	Material	Size [mm]				
		L	d	s	d_1	r_ε
ADMX160608SR	8230	16.00	9.95	6.25	4.50	0.80
ADMX160616SR	8230	16.00	9.95	6.25	4.50	1.60
ADMX160632SR	8230	16.00	9.95	6.25	4.50	3.20

II: *Technical parameters of shell end milling cutter NAREX 63x40 HSS 90*

Type	Material	Size (mm)			
		Big diameter	Small diameter	Length	Number of teeth
NAREX 63x40 HSS 90	19 810	60	27	40	12

III: *Chemical composition of steel 12 050*

Type according to ČSN norm	Chemical composition [%]									Points of conversion [°C]			
	C	Mn	Si	Cr	Mo	V	W	Ni	Other	Ac_1	Ac_3	Ar_1	Ar_3
12 050	0.42	0.5	0.17	0.25	-	-	-	0.30	-	720	780	725	785

IV: *Heat treatment of steel 12 050*

Quenching			Tempering		
Austenitizing [°C]	Time of soaking [min.]	Cooling medium	Heating [°C]	Cooling medium	Dwell [min.]
800	20	water	300	air	20

V: *Hardness of the materials used*

Machining and machined material	Number of measurements					Average [HRC]
	1 [HRC]	2 [HRC]	3 [HRC]	4 [HRC]	5 [HRC]	
ADMX160608SR	72	73	73	73	73	72.8
ADMX160616SR	73	72	72	73	73	72.6
ADMX160632SR	73	72	73	72	72	72.4
NAREX 63x40 HSS 90	59	61	61	60	61	60.4
Machined material steel 12 050	18	17	17	17	17	17.2

machining material to receive shockloads meeting the machined material. On five samples of each cutting tip, hardness using HRC method has been measured, see Table V. Hardness of cutting edge of milling cutter HSS 90 has also been measured. From the average, it is obvious that the resulting hardness is influenced mainly by chemical composition and heat treatment of the material. Hardness of cutting edge of milling cutter HSS 90 has been measured.

Metallographic evaluation of machining materials

The aim of the metallographic observation is to determine main structures of used materials. Current trend is to use highly resistant sintered carbides Fig. 1.

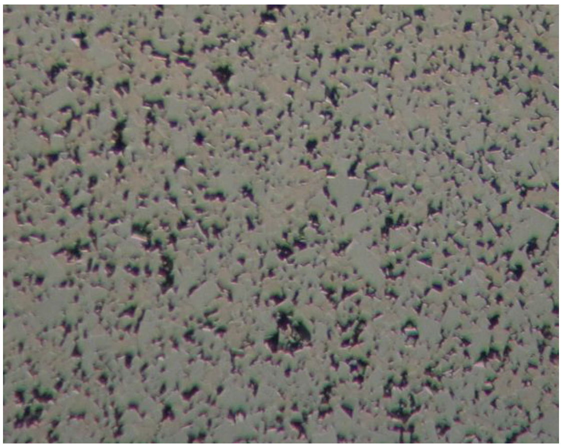
As it is apparent from Fig. 1, it is sintered carbide of middle graining. The base material is WC, which is fitted into a cobalt matrix. Sintered carbide is produced by stamping powder composition of hard carbide particles with powder cementing metal (mostly cobalt), followed by sintering at the temperature close to the melting point of metallic bond (Humár, 2008).

However, the use of sintered carbide is not universal. The disadvantage is lower ductility and high price. Based on this reason, rapid steel HSS (see Fig. 2) is currently more widely used.

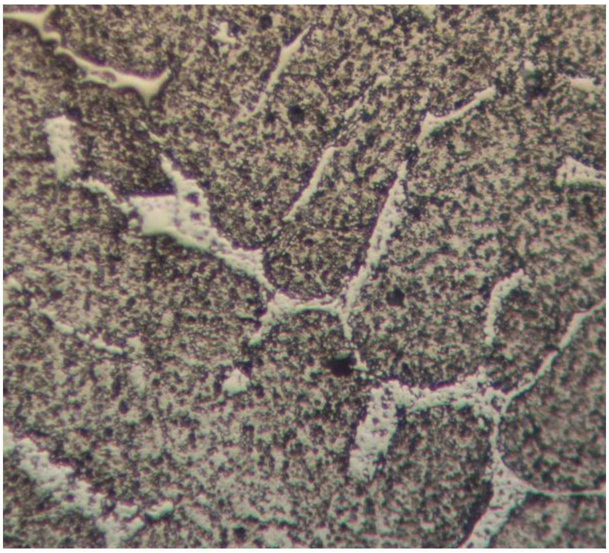
As it is apparent from the Fig. 2, eutectic carbides form a framework which is visible only in moulded form. First structure phase is formed by carbides WC, which themselves form a carbide windrow. The other phase is formed by ledeburit, which is the reason to call rapid steels ledeburitic steels. It is rapid steel which contains about 1.3% of carbon (Morávek, 1972).

Structure analysis of steel 12 050

Cutting operation was processed on heat treated steel 12 050, which is a kind of steel suitable for treatment. It is used mostly for middle stressed machine parts, such as shafts, geared wheels, arbors of machining tools etc. Samples were heat treated, the reason for which was to increase hardness of



1: *Sintered carbide WC, magnification: 400 times*



2: *Microstructure of steel 19 810 (moulded), magnification: 400 times*

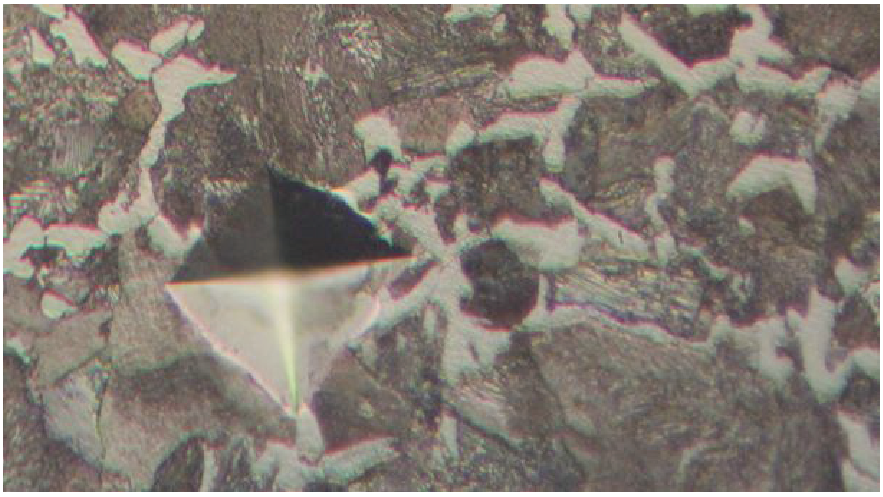
3: *Structure of the basic material steel 12 050 (after heat treatment), magnification: 400 times*

the basic material; used heat treatment is written in Tab. IV. Current trend in engineering is to process final operations on heat treated machine parts which causes an increase in hardness of machining tools and cutting speeds.

The basic material is in its whole cross section formed by sorbite structure. Sorbite is oriented according to the original rough needles of martenzite, see Fig. 3. It is a mixture of ferrite and cementite (Jech, 1977). The more small-grained structure, the more sturdy and hard the material is. Such structure is suitable for machine parts with high demand on surface roughness *Ra*. Due to the risk of causing crashes in the basic material, overheatment of the basic material has to be prevented (Řasa, 2005).

Microhardness of structure phasis of used materials

Microhardness was measured by Hanemann microhardness terster which forms a part of metallgraphic microscope Neophot 21. It is a classical method according to Vickers. A diamante cone with apex angle of 136° is pressed into the material with the pressure of 0.9806 N. According to the length of diagonals, the microhardness HV is read.



4: *Incision by Hanemann microhardness tester, magnification: 400 times*

VI: *Values of microhardness of the individual structure phases of tested materials*

Used material	Ledeburite [HV]	Carbides Milling cutter HSS [HV]	Sorbite [HV]	Carbides cutting tip [HV]
ADMX160608SR-M	-	-	-	956
HSS 90	718	908	-	-
Steel 12 050, tempered 300 °C	-	-	472	-

VII: *Cutting conditions of tools*

Cutting materials	Turnings [min⁻¹]	Movement		Depth of cutting [mm]	Cutting speed [m·min⁻¹]
		On tooth [mm·tooth]	On turning [mm]		
ADMX160608SR	355	0.046	0.280	1	70.226
	710	0.023	0.140	1	140.522
	1 400	0.012	0.071	1	276.948
ADMX160616SR	355	0.046	0.280	1	70.226
	710	0.023	0.140	1	140.522
	1 400	0.012	0.071	1	276.948
ADMX160632SR	355	0.046	0.280	1	70.226
	710	0.023	0.140	1	140.522
	1 400	0.012	0.071	1	276.948
HSS 90	250	0.013	0.160	1	49.455
HSS 90	355	0.009	0.112	1	70.226

Microhardness was measured on 3 samples of each material, five readings from each individual sample were made and an arithmetical average was counted. The individual readings are recorded in Tab. V. Calibration of Hanemann microhardness tester was made on etalon made of steel 11 373, see Fig. 4.

Steel of the calibrating sample is normalized and the structure is formed by lamellas of perlite. Etalon has to be polished before each measurement in order to prevent influence of oxidic coating of the sample surface.

Cutting conditions

Various materials of cutting tools require different cutting conditions. There were used such cutting conditions which were recommended by producers: the minute movement of cutting tips was 100 mm/min (gear ratio: 112) and the movement of HSS 90 was 40 mm/min (gear ratio: 40), see Tab. VII.

Cutting speed v_c was counted according to the below mentioned relation:

$$v_c = \frac{\pi \times D \times n}{100_0}, \text{ [m·min}^{-1}\text{]}$$

where
D ...... diameter of a tool [mm]
n number of turnings [min^{-1}].

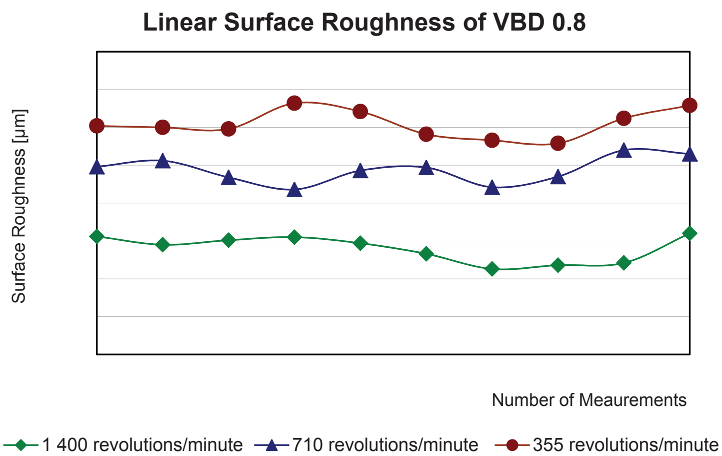
Machine movement of milling machine was selected in the range recommended by the producer. for cutting tips VBD ADMX160608SR f_{min} 100–200 [$mm \cdot min^{-1}$], for rapid steel HSS 90 f_{min} 20–60 [$mm \cdot min^{-1}$].

Movement on turning of a tool is and movement on tooth were computed according to the following relations:

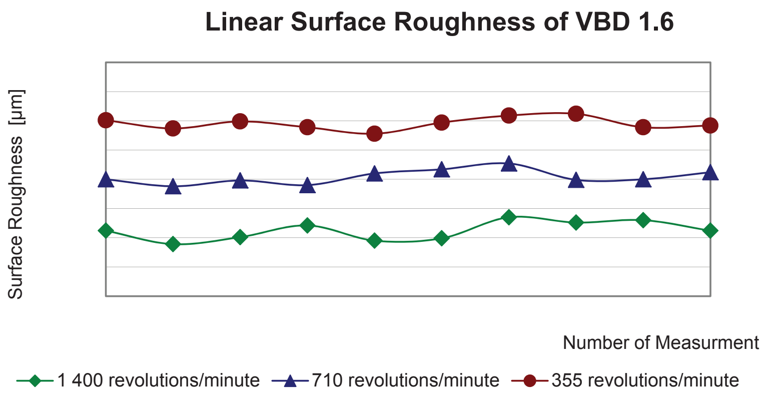
$$f_{ot} = \frac{f_{min}}{n}$$

$$f_z = \frac{f_{ot}}{z},$$

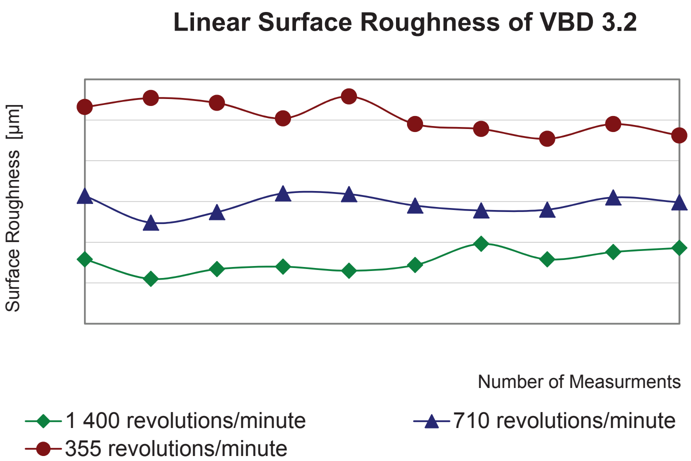
where
f_{min}.... minute movement [$mm \cdot min^{-1}$]
n .... number of turning of a tool [min^{-1}]
z .... number of teeth of a tool.



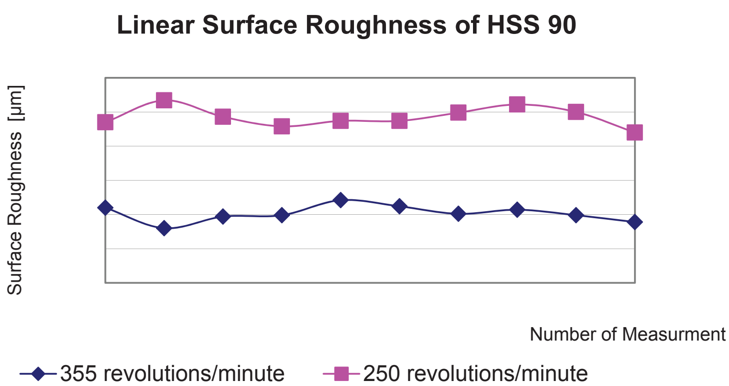
5: *Surface roughness with using a cutting tip ADMX160608SR*



6: *Surface roughness with using a cutting tip ADMX1606016SR*



7: *Surface roughness with using a cutting tip ADMX1606032SR*



8: *Surface roughness with using rapid steel HSS 90*

Measurement of roughness of machined surface

Milling was processed on a knee and column type milling machine with tools and under conditions mentioned in above mentioned tables. Measurement of roughness Ra of machined surfaces was made in two levels (linear and cross) with SURFTEST SJ 201. The outcomes from measurements of linear level are depicted in Fig. 5–8 and the outcomes from the cross level are written in Tab. VIII.

CONCLUSION

Cutting operation forms about 80% of world-wide production of machine parts. The most used are the following: turning, milling and drilling. In order to produce a quality surface, there has to be selected an appropriate tool, which is able to resist not only high cutting speeds and collisions but also high temperatures in the cross cut (Baránek, I2004).

Based on the processed experiment, different abrasive wear of individual parts of cutting tips

VIII: *Values of cross roughness Ra*

Cutting Tools	Revolutions per minutes	Number of Measurement										Average [µm]	Standard deviation [µm]	Variation coefficient [%]
		1	2	3	4	5	6	7	8	9	10			
	1400	1.48	1.34	1.67	1.55	1.71	1.70	1.55	1.49	1.45	1.55	1.55	0.11	7.22
ADMX160608SR	710	2.28	2.55	2.34	2.24	2.41	2.46	2.61	2.4	2.35	2.21	2.39	0.12	5.14
	355	3.22	3.25	3.12	2.94	3.32	2.99	2.95	2.85	2.99	3.12	3.08	0.15	4,76
	1400	1.09	1.00	1.21	1.03	0.95	0.87	1.00	1.13	0.98	0.85	1.01	0.11	10.43
ADMX160616SR	710	2.00	1.86	1.99	1.76	2.02	2.19	1.94	1.95	2.08	2.21	2.00	0.13	6.53
	355	3.31	3.34	3.45	3.47	3.28	3.12	3.15	3.61	3.45	3.59	3.38	0,16	4.70
	1400	0.7	0.97	0.95	0.88	1.01	0.89	0.95	0.87	0.99	1.09	0.93	0.10	10.68
ADMX160632SR	710	1.17	1.34	1.4	1.21	1.45	1.60	1.62	1.43	1.65	1.41	1.43	0.15	10.83
	355	2.26	2.12	2.31	1.99	2.35	2.21	2.24	2.24	2.08	2.12	2.19	0.11	4.83
HSS 90	250	5.15	5.67	5.45	5.71	5.34	5.39	5.46	5.48	5.51	5.66	5.48	0.16	2.94
	355	4.23	4.34	4.51	4.59	4.70	4.56	4.61	4.34	4.32	4.51	4.47	0.15	3.26

of machining tools were proven. Technology of drilling of composite materials is a classical example (Sedláček, 2008).

When machining inhomogeneous materials, composites and heat treated steels, a problem with ductility and tenacity of machining tools appears. There is a risk of deformation of cutting tip. Coating of rapid steels by coatings CVD (Chemical Vapor Deposition) may be taken as one of possible ways of preventing the deformation. These coatings have a high hardness and perfect adhesion characteristics.

This paper deals with surface roughness of machined edge depending on material used for cutting tools (different radius VBD or HSS 90), but also depending on cutting conditions during the milling process. In order to increase the abrasive stress, heat treated steel 12 050 was used in the milling process. According to the processed tests, even in minimal cutting speeds inadequacy of milling cutter HSS 90 was proved – in 355 revolutions per minute the surface roughness was about 4.0 µm and in 250 revolutions per minute the roughness was 5.5 µm. The hardness of this tool is by 12 units HRC lower than the hardness of sintered-carbide tips.

The reason is microstructure of the material itself – ledeburite originating in heat treatment is not able to bear mechanical stress and causes excessive blunting during the milling process. Microstructure of sintered carbide tips is formed by wolfram carbide placed in cobalt matrix. This material is highly stable and there have not been any changes of cutting edge geometry. Cutting speeds can be higher as sintered carbide is able to stand higher temperatures during the machining process.

Linear relation between surface roughness and used radius of VBD was proved in the experiment. Best results have been reached with ADMX160632SR using 1,400 revolutions per minute. The average value of cross roughness Ra was 0.76 µm.

The only quality criterion used in this paper is roughness of the machined surface. However, this criterion is only a part of evaluation of cutting tools.

SUMMARY

The aim of this paper is to analyse materials used for production of cutting tools for cutting operation. Based on selected cutting speeds, turnings and cutting angles, roughness of machined surface was evaluated. Tools made of rapid steels and sintered carbides were chosen for this experiment.

According to the measurements of microhardness, renewable tips is made of sintered carbide have a higher hardness (72 HRC) than rapid steel with ledeburite structure (60 HRC). The basic material for machining was heat treated steel 12 050, which had hardness of 17 HRC. Such an increased value of hardness was selected due to the need of higher stress of cutting tools.

Roughness of machined surface was measured in both linear and cross feed. Roughness deviation Ra in both directions is negligible. At maximal cutting speed of 276.9 m/min., the difference between the two roughnesses is about 0.2 µm. The measured values have shown that slintered-carbide tips with radius of 3.2 mm perform lowest roughness of machined surface (0.76 µm) at the turnings 1,400 min^{-1} s with movement of 0.012 mm·tooth. The reason is a rapid chip removal from the place of heat stress of tool cutting edge. The highest roughness (3.05µm) was observed when milling with replicable cutting tips 0.8 mm with lowest turnings of 355 min^{-1}, the movement was just 0.046 mm·tooth. According to the experiment outcomes, there can be stated that low speed is unsuitable for milling with sintered carbide.

Milling with milling cutter HSS 90 has shown much higher surface roughness than sintered-carbide tips. Even though the experiment was made under recommended cutting conditions, it is apparent that this steel is not able to resist machined material of higher hardness. The best roughness (4.02 µm) was achieved when the milling movement on tooth was 0.009 and the cutting speed was 70.2 $m \cdot min^{-1}$. Generally, tools made of rapid steel can be recommended for millings with lower movement on tooth and lower cutting speed. However, the big advantage of these materials is the possibility of their repeated resharpening; on the contrary replaceable cutting tips cannot be sharpened.

Based on the outcomes of the experiment, the radius of the tool tip has crucially influences the roughness of machined surface. Radius of the cutting edge affects the total microgeometry and thus the overall surface quality. In the meeting part of cutting tool and machined material, there originates a surface not only by machining but also by straining.

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