tool flank wear. The experimental results showed that, when the flank wear of cutting tool is on the increase, the values of the passive force and the cutting temperature are significantly higher. The main cutting force did not change significantly. The chip segmentation disappeared from flank wear VB=0.2 mm. The highest difference of values measured between VB=0 and VB=0.5 mm values of flank wear is 181.8 % in the case of cutting temperature, 492.3 % in the case of passive force is, 135.5 % in the case of the main cutting force, 570.4 % in plastic strain. It was found that, if the flank wear is higher than VB= 0.3 mm, it is express by harmful to the geometrical accuracy and the surface quality of the machined parts.

ACKNOWLEDGEMENT

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References: **1.** *Poulachon G., Moisan A.L.:* Hard turning: Chip formation mechanisms and metallurgical aspects. Transactions of ASME, Vol. 122, 2000, pp. 406-412. **2.** *Remadna M, Rigal J. F.:* Evolution during time of tool wear and cutting forces in the case of hard turning with CBN inserts. Journal of Materials Processing Technology Vol. 178, 2006, pp.67-75. **3.** *Zhang Y. C., Mabrouki T., Nelias D., Gong Y. D.:* Chip formation in orthogonal cutting considering interface limiting shear stress and damage evolution based on fracture energy approach. Finite Elements in Analysis and Design Vol. 47, 2011, pp.850-863. **4.** *Zhen B. H., Komanduri R.:* Modelling of Thermomechanical Shear Instability in Machining. International Journal of Mechanical Science Vol. 39, No. 11, 1997, pp.1273-1314. **5.** *Davim J. P., Maramhao C.:* A Study of Plastic Strain and Plastic Strain Rate in Machining of Steel AISI 1045 Using FEM Analysis. Materials and Design, Vol. 30, 2009, pp.160-165. **6.** *Davim J. P., Maramhao C.:* Finite element modelling of machining of AISI 316 steel: Numerical simulation and experimental validation. Simulation Modelling Practice and Theory, Vol. 18, 2010, pp.139-156. **7.** *Umbrello D., Rizzuti S., Outeiro J. C., Shivpuri R., M'Saoubi R.:* Hardness-based flow stress for numerical simulation of hard machining AISI H13 tool steel. Journal of Materials Processing Technology Vol. 199, 2008, pp.64-73. **8.** *Beňo J., Maňková I.:* Experimental and Modelling Procedures for Cutting Zone Phenomena. XXV. microCAD International Scientific Conference (Production engineering and Manufacturing Systems), 31 March-1 April 2011, pp.11-16 ISBN 978-963-661-965-7. **9.** *Al-Zkeri I.:* Finite Element Modeling of Hard Turning. VDM Verlag Dr. Müller. Saarbrücken, 2008. ISBN: 978-3-639-110340. **10.** ČSN 41 4220/ISO 683/11-70. **11.** Third Wave Advant Edge™ User's Manual, Version 5.3. **12.** *Poulachon G., Moisan A., Jawahir I. S.:* On modelling the influence of thermo-mechanical behaviour in chip formation during hard turning of 100Cr6 bearing steel. Annals of the CIRP Vol. 50/1, 2001, pp.31-36.

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SURFACE INTEGRITY OF HONING

О. ЗАБО
ШОРСТКІСТЬ ПОВЕРХНІ ПРИ ХОНІНГУВАННІ
Складові поверхневої якості значно впливають на експлуатаційні властивості. Тип механічної обробки, використовуваних інструментів і технологічні особливості впливають на шорсткість і мікротопографію поверхні після механічної обробки й на її трибологічні властивості. У статті запропоновані важливі трибологічні й поверхневі характеристики точності оброблених поверхонь при хонінгуванні, а також методи для їхнього визначення.

Составляющие поверхностного качества значительно влияют на эксплуатационные свойства. Тип механической обработки, используемых инструментов и технологические особенности оказывают влияние шероховатость и микротопографию поверхности после механической обработки и на ее трибологические свойства. В статье предложены важные трибологические и поверхностные характеристики точности обработанных поверхностей при хонинговании, а также методы для их определения.

Component surface quality greatly influences the working properties. Type of machining, the applied tools and technological characteristics have an effect on the roughness and microtopography of the machined surface and on their tribological properties. The article introduces important tribological and surface roughness characteristics of honed or microfinished surfaces and suggests methods for their determination respectively.

1. SURFACE QUALITY OR INTEGRITY

Deterioration of machine elements in most cases is the consequence of various abrasion, fatigue and corrosion stresses, which have a very close relationship with the surface quality of the components.

Surface quality of the components is determined by surface microgeometry (2D and 3D) and properties of the layers close to the surface (texture, remaining stress and microhardness) [1, 4]. Surface quality improvement microfinishing procedures (grinding, honing, superfinishing, lapping, microfinishing) are mainly designed and applied for cylindrical, and polygon, plane surfaces [2].

Surface quality improvement and decreasing the roughness of the surface generally have a positive influence on the tribological characteristics of the components. Attention will be paid to the relationship between surface microtopography and tribology.

2. TRAJECTORIES AND SURFACE MICROTOPOGRAPHY

Arithmetical mean deviation R_a from the mean line of the profile or maximum height of irregularities R_{max} or height of irregularities R_z given on the drawings of the components give insufficient requirements for the microgeometrical picture of the component.

The values R_a, R_{max}, R_z and similar surface roughness index-numbers characterize the surface microgeometry of the component in one direction - in the direction of depth. From the aspects of load capacity, lubrication, etc. formation of the surface microtopography is also decisive.

More information is contained in supplementary specifications which also determine the finishing method of the component, e.g. the specification „honed” (Hungarian standard) on the blueprint.

Table 1 – Component of motion, compound motion

Figure		A	b	c	d
Motions	N	$v_{th} \rightarrow$; $v_{ah} \uparrow\downarrow$	$v_{th} \rightarrow$; $v_{ah} \uparrow\downarrow$	$v_{th} \rightarrow$; $v_{ah} \uparrow\downarrow$	$v_{th} \rightarrow$; $v_{ah} \uparrow\downarrow$
	O	- -	$\vec{v}_{trh\leftarrow}$ -	- $v_{tra} \uparrow\downarrow$	$\vec{v}_{trh\leftarrow}$ $v_{tra} \uparrow\downarrow$
Operation		Honing (normal)	honing + tangential oscillaltion	honing + axial oscillation	honing + axial and tangential honin
Figure		E	f	g	h
Motions	N	$v_{th} \rightarrow$ -	- $v_{ah} \uparrow\downarrow$	- $v_{ah} \uparrow\downarrow$	$v_{th} \rightarrow$ -
	O	- $v_{tra} \uparrow\downarrow$	$\vec{v}_{trh\leftarrow}$ -	- -	- -
Operation		Tangential profiling + axial oscillation	axial profiling + tangentila oscillation	axial profiling	tangential profiling

Note: N = normal motions; O= oscillation motions

1. Example machine b): SzFS 63x315B typ. Naumburg – Honmaschine, etc.
2. Example machining: [2] Quasi honing

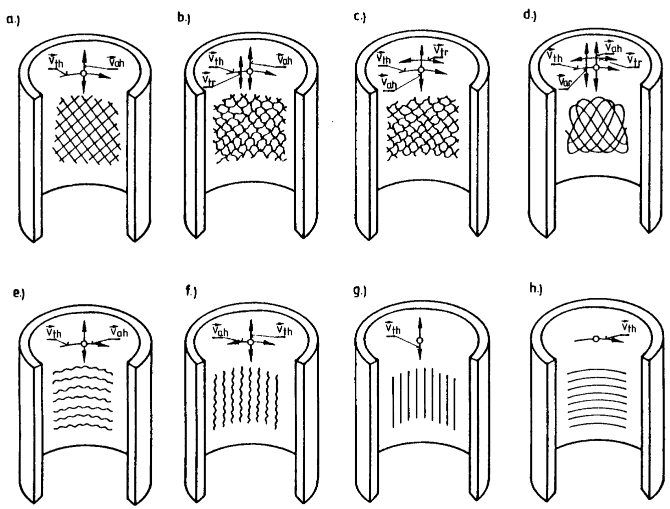

Figure 1

In finishing jobs, superposition of basic motions and further motions is possible. For example, short-stroke oscillatory motion is added to long-stroke motions, which are achieved in some honing machines.

Figure shows trajectories that can be formed by the honing of bores. Resultant velocity of the motions (in an upright coordinate system fixed to workpiece) are as follows:

$$\vec{v} = \vec{v}_{th} + \vec{v}_{ah} + \vec{v}_{tr} + \vec{v}_{ar} \qquad (1)$$

where: $\vec{v}_{th}$ and $\vec{v}_{ah}$ are tangential and axial velocity components of long-stroke honing; $\vec{v}_{tr}$ and $\vec{v}_{ar}$ tangential and axial velocity components of short-stroke honing. Several motions can be superposed on each other, which is described by the initial vector equation. The interconnection of the motions or their absence can be seen in Fig 1.

Signs and abbreviations used in figure 1.: $\vec{v}_{th}$ and $\vec{v}_{ah}$ are the tangential and axial components of the long-stroke motion, resp., $\vec{v}_{tr}$ and $\vec{v}_{ar}$ are the short-stroke relatively higher frequency tangential and axial motion components superposed on the previous vector components.

For example, Fig. 1/g. can be considered to be honing by linear cutting motion or "quasi-honing" in the authors terminology [2].

3. MICROGEOMETRICAL CHARACTERISTICS, MATHEMATICAL DESCRIPTION

In order to assess the conditions of contact between the coupling surfaces, the microgeometrical mapping of the surfaces - the measurement of the microtopography - is the first step. Surface roughness profile curves taken at various places and in various directions of the surface contain masses of information. The surface roughness profilogram of surfaces machined by multigrain abrasive tools - as honing - shows a large number of random irregularities (characteristic of tool, material tear-offs, etc.) and periodical regularities originating from the type of the procedure (depending on the kinematics of the procedure).

Surface roughness profile of the components H(x) can be described by a normalized, stationary stochastic function. Correlation function K(t) can be formed by transformation from surface roughness curve H(x), which consists of aperiodic and periodic parts:

$$K(t) = \sigma^2 \left[\sum_{I=O}^{m} A_i \exp(-a_i|t|) + \sum_{i=o}^{n} A_j \exp(-a_j|t|\cos\omega_j t) \right] \qquad (2)$$

where σ - square mean deviation of the heights of irregularities of the profile from mean line of the surface roughness profile "M" ("M”-system); A_i, A_j, a_i, a_j, and ω_j- parameters of the correlation function; t- abscissa axis of the correlation curve. Exact computation with relationship (2) is very complicated. For routine computations, approximation with the first two terms gives a result of sufficient accuracy.

Three characteristic types of the function K(t) can be separated. These curves are aperiodically decreasing, oscillating damping and periodically oscillating respectively The last one is not characteristic of surfaces of irregular roughness. For surface roughness profile defined in the system "M" (see: Hungarian standard MSZ 4721) the expected value $M_o = M(\xi)$ becomes $M_o[H(x)] = 0$. After abrasive machining the density function of the surface roughness peaks] can be given by a Gaussian normal distribution function [3]:

$$f[H(x)] = \frac{1}{\sigma\sqrt{2\Pi}} \exp\left[-\frac{H^2(x)}{2\sigma^2}\right] \qquad (3)$$

Expected value of the arithmetical mean deviation from the mean line of the profile R_a, if $|h(x)| = H_x$ and L the is base-or traversing length is as follows

$$M_o(R_a) = \frac{1}{L}\int_o^L M_o[|H_x(x)|]dx = \frac{1}{L}\int_o^L \int_o^\infty H_x f(H_x) dH_x . dx \qquad (4)$$

After derivation we get

$$M_o(R_a) = \sigma\left[\frac{2}{\Pi}\right]^{0,5} = h_q\left[\frac{2}{\Pi}\right]^{0,5} \cong 0,8.h_q \qquad (5)$$

where h_q - quadratic mean deviation of the irregularities. Examining a plane surface or surface rectified in plane, protrusion of the surface roughness peaks is characterized by probability field H(x; y), the correlation function of which is $K(t_1;t_2)$ and in the system "M" $M_o[H(x;y)] = 0$ (here:M is the mean plane).

The mean surface roughness

$$R_a(x;y) = \frac{1}{A}\iint |H(x;y)| dx\ dy \qquad (6)$$

where A - the surface of the examined region of the surface roughness. Its expected value is

$$M_o[R_a(x;y)] = \sigma\left[\frac{2}{\Pi}\right]^{0,8} \cong 0,8.h_q \qquad (7)$$

For example the expected values of the protruding of the roughness peaks $M_o(H_{max})$ and their distance $M_o(s)$ can be examined by a similar way. In addition, relative reference length ratio of the profile of a given microgeometry is

$$t_p = L^{-1}.\sum_{i=1}^{n} b_i \qquad (8)$$

The index-number t_p provides a great of information for the judgement of wear resistance and contact rigidity of the surface. In relationship (8) Σb_i - is the

sum of line lengths cut by the line parallel to the mean line from the profile within the base length L.

The variable c_x by the bearing length curve $t_p = t_p(c_x)$ is called the height of the profile section. From the highest protruding peak in to the direction of the material (perpendicular to mean line M) a value c_{xo} = const. (e.g. $c_{xo} = 0.1R_{max}$) has a bearing section t_{po}, according to which the bearing capability of different surfaces can be compared. The bearing ratio is often given in percentage values. The bearing curve of the profile curve H(x) with mean line M is

$$t_p = \frac{1}{L}\int_o^L \xi[H(x); c_{xo}]dx \qquad (9)$$

where $\xi=1$, if $H(x)c_{xo}$ and $\xi=0$, if $H(x)\leq 0$. The expected value of t_p at level c_{xo} and for $H(x)>c_{xo}$ is.

$$M_o[t_p(c_{xo})] = \frac{1}{L}\int_o^L M_o[\xi(H;c_{xo})]dx = \frac{1}{L}\int_o^L \int_o^\infty f(H)dH\ dx = 1 - \phi\left[\frac{c_{xo}}{\sigma}\right] \qquad (10)$$

where ϕ - distribution function of probability variable of standardized normal distribution. For plane surface analogously with the computation of the $R_a(x;y)$ the expected value of the relative bearing surface for c_{xo} level is obtained, which is identical with relationship (10).

4. EXPERIMENTAL FINDINGS

The microgeometrical bearing ratios t_p for varius values of c_x measured on a surface roughers testing instrument, Perthometer Type S10D and S8P and FOCODYN unit operating with laser-beam are shown in Figure 2. The conditions of plotting the diagrams in Figure 2 are as follows.

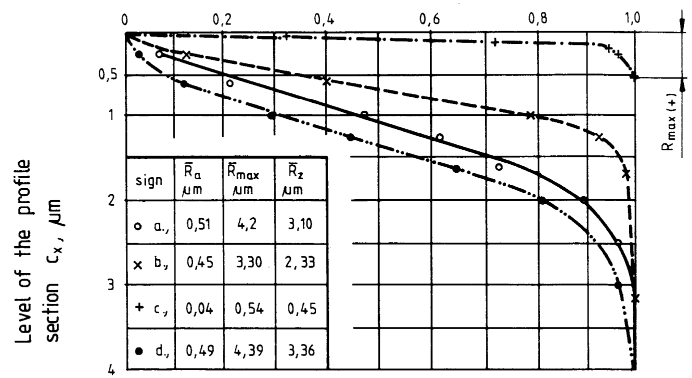

Figure 2/a – Bearing curves, surface roughness characteristics of honed (a-c) and grinded (d) surface

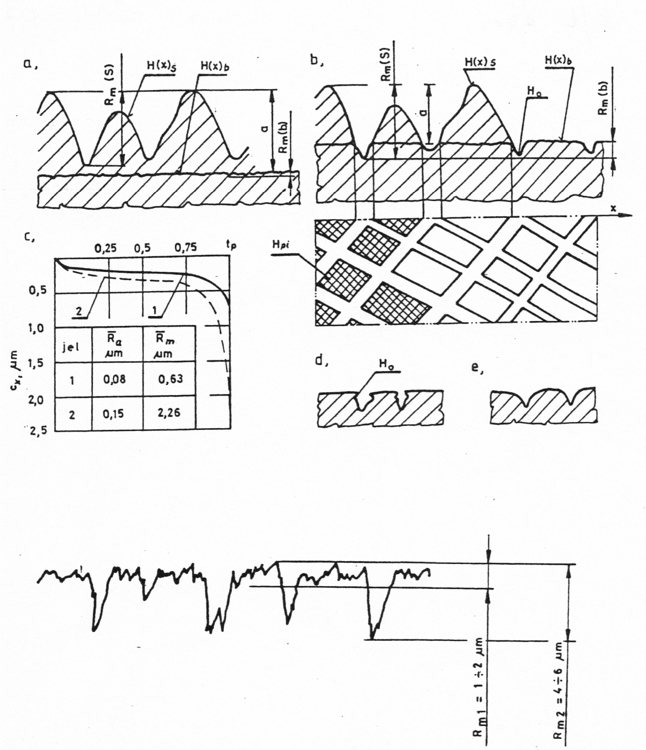

Figure 2/b – Bearing curves (c), surface roughness characteristic of grindig (a), of plateau-honing (b,d,e and profilogram)

a, - finishing honing with synthetic diamond tool: ACM 28/20-M1-100%; b, - smoothing honing (ACB 160/125-M1-100%); c, - roughing honing (ACB 250/200-M1-100%) and d, - smoothing grinding. Development of the bearing ratio is very clear. Material of workpiece: G03 hardened ball bearing steel; HRC 60±2. The new instruments draw the bearing curve and calculate the surface roughness characteristics. It is shown in Figure 3. Type of applied instrument: „Perthometer".

A great deal of information on the surface is offered by the surface roughness diagrams, but more information is available from scanning microscope shots. Type of applied scanning microscope is: JOEL-JEM 100 B. The microtopography, bearing surface, oil-bearing capability of the surface etc. can be judged visually to an adequate extent [3]. Figure 4. is a scanning microscopic picture (magnifyting 400x) of a surface machined by smoothing grinding (Fig.2.d.), Figure 5. is that of a honed surface of smoothing type (Fig.2.b.). The characteristic scratch-system, the depths, number and direction of scratches on surface unit also support the favouring tribological properties of honed surfaces.

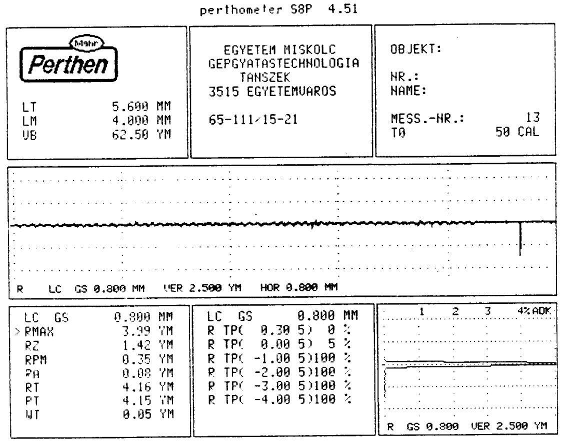

Figure 3 – Measured surface roughness characteristics of honed surface

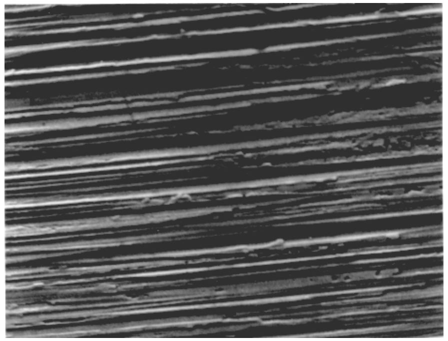

Figure 4 – Scanning-microscope picture of grinded surface

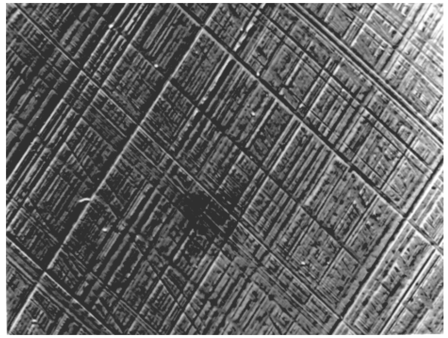

Figure 5 – Scanning-microscope picture of honed surface (finishing honing)

5. QUALITY SURFACE AS A FUNCTION OF THE WORKING AND MACHINING CHARACTERISTICS

Given working conditions (load, friction, lubrication, speed, etc.) determine the optimum surface quality of the pairs of components joining with or moving on each other and the finishing procedure to be selected together with its characteristics. It is evident that e.g. the optimum surface roughness of the races of ball bearings is R_a = 0.06 μm, and it is advisable to achieve it by superfinishing (Figure 6.) [3]. For differing surface roughnesses t_{b1} = 16 hours in running is needed. In case of initial surface roughness less than optimum too, surface roughness of the ball path in running increases. Thus, it is useless to produce surfaces finer than optimum, whats more, it causes operational cost increment.

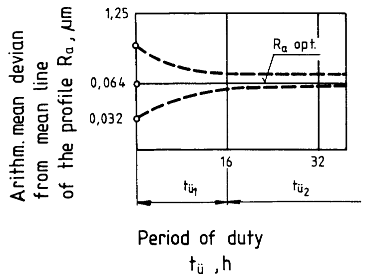

Figure 6 – Variation of the surface roughness at the wearing-in of ball bearing

Observations in the vehicle industry showed the same results (honed cylinder sleeves, superfinished cylinder pins, etc.). Under other working conditions the initial surface roughness of the pairs of components can be essentially larger. Finishing improving surface quality is mostly preceeded by grinding. The cutting zone temperature in grinding reaches 500-2000°C, which causes metallographic transformations in the surface layers of the component. The cutting forces acting here deform the surface layer. It is shown by means of electron diffraction tests that the surface layer that gets physically and chemically deformed is minimum 0.005 mm thick even after finishing grinding [2].

It is unfavourable for the durability of the component. Honing, superfinishing and lapping separates these transformed layers by microcutting, in which there will occur no further unfavourable deformations, or only to a negligible extent. For example in finishing machining, (honing) heating of the component may be maximum 60-120°C.

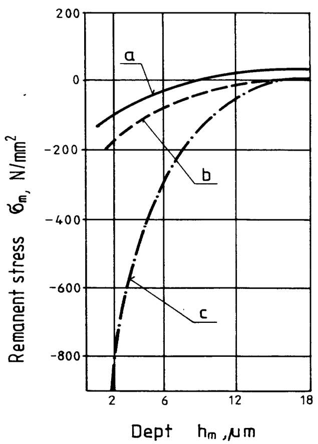

Figure 7 – Remaining stress of the surface layer after honing

By means of adequate technology compressive remaining stress condition and hardened surface layers can be developed that increase the endurance limit and wear resistance of the component of running low value compressive remaining stress will be obtained for expedient for technological data (Figure 7, curves a,b). Circumferential velocity and pressure of the tool can be adjusted so that the lapping and ironing effect of the cutting prisms will dominate. It causes slight plastic deformation of the surface layer, and relatively large compressive stresses will remain in the surface layer. The compressive remaining stress increases the endurance limit of the component.

6. CONCLUSIONS

The surface quality of surfaces honed, superfinished and lapped by means of adequate technology is favourable from the aspect of wear resistance, endurance limit, and lubrication. Friction losses of the pairs of components in motion and the stick-slip effects (e.g. positioning and fine adjustement mechanisms) decrease. With synthetic diamond tools, these advantages increase, and in addition, procedures become more productive and components of heat and corrosion resistant steel difficult to machine (KO38, KO13, etc.) can be made with favourable tribological parameters. Complex surface quality tests and evaluation must be carried out for finishing jobs. Data calculated and measured correlate reasonably well.

For the examination of polygon bores machined by means of "quasi-honing" and shafts made on an ultraprecision lathe, the procedures have been applied [2] with success.

Therefore surfaces with favourable tribological properties can be produced.

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References: 1 Whitehaus, D.: **Surfaces and their Measurement**. Hermes Penton Ltd, London, 2002. 395. **2** Szaby, Otty: **Optimisation of Technology and Qusi-Honing of Polygon-Bores.** Journal of Materials Processing Technology, V.119: 1-3. December 2001. pp.117-121. **3** O. Szaby: **Tribological Characteristics of Honing.** AUSTRIB '94 4th International Tribology Conference. December 5-8. 1994. Perth, Western Australia. Book of Conferenc, pp.631-696. **4** Kundrбk J., Gyбni K., Bana V.: **Rougness of ground and hard-turned surfaces ont he basis of 3D parameters**. International Journal of Advansed Manufacturing Technology. V.38. 2008. 1-2. pp.110-119.

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