

V. Lavrinenko, Kyiv, Ukraine,
V. Solod, Kamianske, Ukraine

THE RELATIONSHIP BETWEEN THE PARAMETERS OF ROUGHNESS AND FEATURES OF SURFACE FORMATION WITH A SPECIAL MICROPROFILE

Abstract. *This article shows the regularities of the formation of the relationship between the parameters of the roughness of the treated surface under the conditions of processing with a tool made of superhard materials. Features of formation of the ratio of height parameters of roughness R_{max}/R_a for conditions of diamond-abrasive processing are shown. In general, in relation to R_{max}/R_a we have a kind of "roughness arc", when first for a normal untreated rough source surface it is close to 4, then abrasive-diamond treatment of this surface raises this ratio to 6 and then to 8, but further methods of abrasive finishing and polishing reduce the ratio to 6 and then chemical-mechanical polishing to a high-quality surface returns this ratio to values close to 4. This means that if the initial cost of grinding the original surface affects the increase in the ratio, then the subsequent cost of finishing and polishing work reduces the value of the ratio R_{max}/R_a to the original. The peculiarities of obtaining a treated surface with a special microprofile, which is a flat protrusions with recesses (a kind of "pockets") for placing oil to increase the service life of such a surface.*

Keywords: *parameters of the roughness; the ratio of height parameters of roughness R_{max}/R_a ; special microprofile.*

INTRODUCTION

An arithmetical average deviation from the mean line R_a is a surface roughness parameter most widely accepted and used in scientific and technical publications. We point out that at one time GOST 2789-73 "Roughness of the surface. Parameters, characteristics and designations" indicated that the roughness parameters (one or more) are selected from the following nomenclature: R_a – arithmetic mean deviation of the profile; R_z is the height of the profile irregularities at 10 points; R_{max} is the highest profile height; S_m is the average step of inequalities; S – the average step of the local protrusions of the profile; t_p is the relative reference length of the profile, where p is the value of the cross-sectional level of the profile. Generalized data on the influence of various machining methods and modes using tools of superhard materials (SHM) on these parameters have not been adequately presented in the literature. Therefore, it is not clear which criteria should be used when deciding upon the machining processes in order to achieve the required R_a value. Furthermore, the experience in commercial operation of products suggests [1] that for various applications more than one surface roughness parameter of contacting surfaces should be monitored:

- R_a and the relative reference length of the profile irregularities t_p for the parts that operate under the conditions of sliding and rolling frictions and for low-wear parts,
- R_a and t_p for the parts prone to contact stresses,
- R_a for press-fit joints,
- maximum height of irregularities R_{max} , maximum peak height R_p and mean spacing of the profile irregularities S_m for the parts subjected to variable loads,
- R_a and t_p for the parts that form tight joints.

In this case, it is also stated that the parameter R_a is preferred. Thus, using this parameter, in [2] the classification of methods of abrasive processing (roughness) – grinding (when R_a is from 100.000 \AA to 1.000 \AA or from 10 \mu m to 0.1 \mu m), lapping (when R_a is from 1.000 \AA to 100 \AA or from 0.1 \mu m to 0.01 \mu m), polishing (when R_a is from 100 \AA to 1 \AA or from 0.01 \mu m to 0.0001 \mu m).

THE PURPOSE OF RESEARCH

Note that there are such persistent misconceptions that the above parameters seem to exist independently and it is possible to obtain any desired value of one parameter and any desired value of another, or, for example, you can act on one parameter, and others will not change. The consequence of such misleading judgments is that researchers separately study the influence of processing regimes and conditions on specific roughness parameters, which introduces a system error, because in fact for the same processing conditions all roughness parameters are interconnected and affect only one parameter is impossible, because others will change. Therefore, the purpose of this article was to identify the features of the relationship between the roughness parameters and to establish how this may affect the achievement of a special microprofile of the treated surface.

RESEARCH DATA

We will illustrate this with a number of existing relationships between the parameters cited in the literature. Note that roughness is a statistical process, so such relationships are largely correlated. In [1], it was shown that the magnitude of the relationship or relationship between the parameters R_z and R_a can vary. The magnitude of this ratio depends on the profile of the roughness combs. Thus, for the triangular profile $R_z/R_a = 4$. For convex and concave profiles, this ratio is larger and can reach up to 8 depending on the degree of convexity and concavity. Thus, the more the profile of the combs differs from the triangular one, the greater the R_z/R_a ratio. Therefore, this ratio can be called as the coefficient of profile shape or the coefficient of completeness of the profile. It is known that the parameter R_z cannot carry information about the shape of the comb. The parameter R_a contains

such information in an implicit form and only the ratio R_z/R_a gives a numerical characteristic [1]. For specific processing conditions in a number of works the values of such relation are shown. Thus, to calculate the height characteristics of the roughness of the workpiece, you can use the following relations: $R_{max} = kR_z$, where $k=1.25$ for irregular and $k=1.15$ for regular roughness. In this case, $R_z \approx 4R_a$ for the rough surface and $R_z \approx 5R_a$ for the surface in the range $R_a = 1.25-0.02 \mu m$. For conditions of processing by diamond-abrasive wheels: $R_z = 5R_a$. For turning with cutters: $R_z = 5R_a$ [1].

Let us now consider the correlation between R_a and R_{max} . Thus, for the conditions of diamond abrasive tool processing – $R_{max}=(8-10)R_a$ [3]. For grinding conditions of coarse-grained CBN (160/125) steels 40X (HRC 53) and SHX15 (HRC 60) – $R_{max}=(6.472 \pm 0.225)R_a$. For EDM conditions: $R_{max} = 5.40625R_a$ [1].

Additionally, we pay attention to the correlation between the parameters: altitude R_a and R_{max} and step S_m . In [3] it was shown that for most methods of machining at an average height of microroughnesses the step of roughness S_m does not exceed $40R_{max}$ (grinding, planing, milling, boring of steel and cast iron parts), and for inequalities with a smaller height, their step values can reach $300R_{max}$. For the conditions of EDM: $S_m=14,1R_a$ [1].

As we can see, the analysis of the literature refutes the constant misleading judgments about the independence of the roughness parameters. But there are other misleading judgments: about the constancy of the ratio R_{max}/R_a or that the step of microroughness S_m increases with increasing parameter R_a . Let's look at these misleading judgments in more detail below.

The first misleading judgment is that the R_{max}/R_a ratio is constant and equal to 5 [4]. The theory of calculation of roughness parameters at grinding is based on this value of the relation. It would be possible to agree with this judgment, because the number 5 is quite decent, which we will show later, but why it is a constant, it is unclear. The identity of the slice thickness and the R_{max} parameter is even more unclear.

The second misleading judgment is that the R_{max}/R_a ratio is not constant and can vary in a wide range: very wide from 1.36 to 109.6 [5], or moderate from 1.42 to 18 [6]. The authors of [5] also indicated that the practice of abrasive treatment has shown that the ratio R_{max}/R_a during grinding mainly takes the value 4...6. This somehow explains the figure above in the first sentence – 5, as the average between 4 and 6. But a little further in [5], its authors point out that in the case of abrasive polishing, the R_{max}/R_a ratio can take the value 30. Let's understand - why such ranges and what it means.

Let's start with work [5]. It performs a theoretical analysis of the nature of the change in the ratio R_{max}/R_a for different conditions of abrasive treatment, and the grains are modeled in the form of a cone and a sphere. The authors assumed that

the parameter R_{max} physically determines the slice thickness a_z by a single grain. Further, the authors argue that during the transition from the cutting process to the process of grain friction with the processed material, the ratio of the height parameters of roughness R_{max}/R_a can vary widely – from 56 to 14. It follows that the process of abrasive polishing can take place under these conditions at $R_{max}/R_a = 30$, and, accordingly, $R_{max}/R = 0.07$, where R is the radius of the abrasive grain, μm . When grinding, as we mentioned above, the ratio R_{max}/R_a takes smaller values (4...6), which corresponds to the values of $R_{max}/R > 0.6$. It is in these conditions, according to the authors [5], is a steady cutting process. That is, the lower the R_{max}/R_a ratio, the better the high-performance material removal. And when the transition from the cutting process to the process of friction of the grain with the processed material, the ratio R_{max}/R_a can take quite large values. Note that the assumptions of this work are certainly interesting and have a right to life. We will analyze them in more detail below. However, the results of theoretical studies of the ratio R_{max}/R_a from 1.36 to 109.6 are surprising.

Now let's deal with the work [6]. Here, too, we are faced with a fairly wide range of R_{max}/R_a ratios from 1.42 to 18. But it should be noted that when the authors of [6] present the results of experimental studies of roughness, they are quite conscious and logical. Thus, with fine diamond grinding of glass, the ratio R_{max}/R_a is 7.2...8.5. When polishing stone with bound abrasive R_{max}/R_a is 4.2...18. When polishing glass K8 $R_{max}/R_a = 7.8...15.0$. But when we encounter in this work with modeling in the framework of the physical-statistical model, the results of calculations of the ratio R_{max}/R_a are surprising. Thus, for monocrystalline silicon carbide, this ratio is 1.5 ± 0.1 . For the polishing of single-crystal sapphire the R_{max}/R_a ratio was 1.8...2.0 [6].

What is the conclusion from the above? Let's pay attention to R_{max} . This is the highest altitude parameter. It is usually greater than R_z . In turn, R_z is greater than R_a . How big? It is known: $R_z \square 4R_a$ for a rough surface and $R_z \square 5R_a$ for a polished surface. Can R_{max} and R_z match? They can. However, R_{max} can never be less than $4R_a$ for polished and polished surfaces, and in fact for all finishing surfaces. That is, the lower value of the ratio $R_{max}/R_a = 4$. And what is the upper value? In order to answer this question, we need to return to the conclusions of the work [5]. The authors of this work accepted that the parameter R_{max} physically determines the slice thickness a_z by a single grain. Let's deal with this. If we accept the above statement, then when grinding, according to the authors [5] the value of $R_{max}/R > 0.6$, where R is the radius of the abrasive grain, μm . Let's see if this is so. To do this, take from work [1] table. 8.2 and slightly refine it (Table 1).

Table 1 – Influence of the concentration of AC4 diamonds with MA coating in circles on the BC-E polymer bond on the roughness indices during electrochemical grinding of TH20 alloy with a productivity of 525 mm³/min

Characteristics of the wheel	Roughness indicators			R, μm	R _{max} /R
	R _a , μm	R _{max} , μm	R _{max} /R _a		
100/80–100	0,36	2,75	7,64	45	0,061
(100/80–100)+(50/40–25)	0,63	2,99	4,75	40	0,075
100/80–150	0,40	3,29	8,23	45	0,073

As you can see, the ratio R_{max}/R when grinding from table. 1 are significantly lower than 0.6, and the ratio R_{max}/R_a correspond to those characteristic of grinding. So what determines the value of the ratio R_{max}/R_a when polishing up to 30 [5], or up to 18 [6]? Determines not a_z [5], but scratches that occur during polishing on the treated surface. And these scratches occur due to the fact that, as we pointed out above, abrasive grains are not homogeneous. Any grain size has only 75... 80% of the main fraction, and up to 10% are grains of higher grain size. Similarly, the strength of SHM grains is not the same, because this indicator is subject to the logarithmically normal distribution law [1], and therefore the grain sample necessarily contains grains of higher grain size and greater strength, and therefore they cause scratches when polishing. In order to get rid of this, it is necessary to either further classify the powders of SHM grains, or to carry out the polishing process in several stages with a decrease in the grain size of the polishing paste.

Let us return to our R_{max}/R_a ratio. And what do the authors themselves suggest? Let's deal with this.

According to our data, this connection is generally reduced to simple relationships. For example, for the sintered and untreated surface of hard alloys, this dependence is close to the form $R_{max} \approx 4R_a$. At blade processing of steels (40X, SHX15, X12M) with cutters from Hexanite-P the ratio corresponds more to the form of $R_{max}/R_a \approx 6$.

For abrasive treatment the most characteristic in this case will be the ratio close to the form of $R_{max}/R_a \approx 8$. This is typical both for the processing of tool materials: high-speed steels, tool ceramics, hard alloys (tungsten and tungsten), and for the processing of stainless steels, titanium alloys and joint processing of hardened and not Hardened steel (steel 10 + 9HF). And can there be other variants of this relation for abrasive processing? We found that they can. The ratio $R_{max}/R_a \approx 6$ is characteristic for abrasive processing of high-speed steels by circles of electrocorundum and diamond processing of magnetohard alloys, when a rougher surface is formed or its contribution to the height parameters are introduced by porosity. In general, it would probably be more correct to assume that for abrasive treatment (in a sufficiently wide range) the ratio R_{max}/R_a is closer to the form

$R_{max}/R_a \square 6-8$, and larger values are also characteristic of pure abrasive treatment methods. But when proving ceramics and coatings, the ratio is close to the form $R_{max}/R_a \square 10$. In the latter case, the porosity of these materials contributes to the relative increase in the value of R_{max} , because it already matters when proving it. The above allowed us to formulate the following position: the rougher the surface, the smaller the ratio between R_{max}/R_a , and the more perfect the surface obtained by proving, polishing or other finishing methods, the greater the ratio. That is, for example, the sintered surface and the surface after abrasive treatment with conventional abrasives have the ratio R_{max}/R_a in the range (4-6). Processing with grinding wheels with SHM, when the surface has a lower roughness than after the above methods, and in fine grinding is mainly characterized by the ratio $R_{max}/R_a \square 8$. In the case of finishing operations on porous materials, when the values of R_a are small, this ratio R_{max}/R_a is already close to 10. Just in this case, the defects of the treated surface in the form of pores or scratches and is the reason for the increase in the value of this ratio.

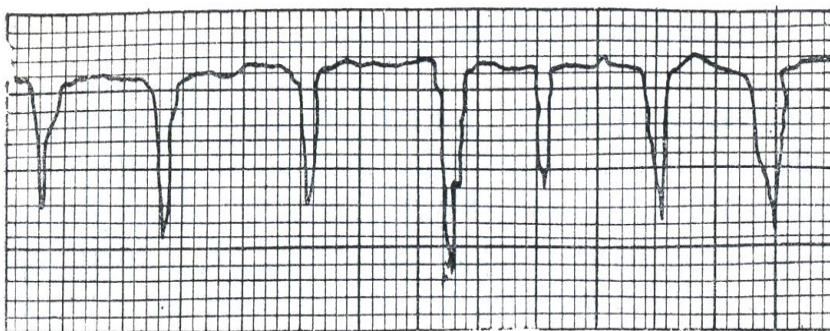
Meanwhile, a number of further studies have shown that this conclusion is incomplete, as it reflects only the first part of this trend. It turns out that if we need to get an even more perfect surface after grinding, for example, polishing to obtain values of roughness values up to 5–10 nm, ie the cost of the process of obtaining the surface increases, the value of the ratio R_{max}/R_a begins to decrease and reaches the situation when the above ratio becomes close to the form $R_{max}/R_a \square 4$. That is, we have a kind of return to the original data in relation.

We will demonstrate the above on the example of forming a polished and polished surface of lithium tetraborate single crystal, a new promising material for functional electronics, the processing of which is very expensive, as it requires a final roughness for parameter R_a within 1 nm [1]. After cutting the single crystal, its grinding was performed with a free abrasive with a decrease in the grain size of the abrasive and it would be logical to assume that the ratio R_{max}/R_a , based on the above, will be within 6 (actually obtained: from 5.25 up to 6.25). Further polishing of lithium tetraborate single crystals was performed on resin polishers using two AFM diamond micropowders with a grain size of 2/1 to 1/0 and chromium oxide. This increases the cost of the process, but can significantly reduce the roughness of the treated surface of single crystals. For example, the roughness of the polished surfaces of single crystals after treatment with AFM 1/0 micropowder corresponds to R_a in the range from 3.5 nm to 6.5 nm. Subsequent use of chromium oxide during polishing can further reduce the roughness. Analysis of the polished surface by atomic force microscopy showed that in the lithium tetraborate single crystal in the plane (100) the microrelief has R_{max} , R_z and R_a , which are 5.26 nm, 4.82 nm and 1.24 nm, respectively, and the ratio R_{max}/R_a is 4.25. The above, just indicates that the more expensive the process of obtaining a high quality surface, the ratio R_{max}/R_a decreases to – 4.

In general, in relation to R_{max}/R_a we have a kind of "roughness arc", when first for a normal untreated rough source surface it is close to 4, then abrasive-diamond treatment of this surface raises this ratio to 6 and then to 8, but further methods of abrasive finishing and polishing reduce the ratio to 6 and then chemical-mechanical polishing to a high-quality surface returns this ratio to values close to 4. This means that if the initial cost of grinding the original surface affects the increase in the ratio, then the subsequent cost of finishing and polishing work reduces the value of the ratio to the original – $R_{max}/R_a=4$.

Thus, the research showed that there is a possibility under certain conditions to fundamentally change the distribution of micro-irregularities on the treated surface, which will increase the fullness of its profile and form a surface with a kind of "oil pockets".

At one time in [7] it was shown that one of the ways to increase the technical and operational performance of the internal combustion engine is the formation on the surfaces of the cylinders of such an engine special microprofile, which is a flat alternating protrusions with recesses (peculiar "pockets") to accommodate the oil (Fig. 1). This increases the oil capacity and the bearing area of the treated surface. As a result, running-in time is reduced, lubrication costs are reduced, cylinder wear is increased and engine life is increased. It is established that the planar apex of such a surface is 50–66 % at the level of the profile cross section $p=1-2 \mu m$ from the line of the maximum protrusion, the depth of the lines for oil placement is 2.5–10 μm . Surfaces of this type can be obtained by blunting the protrusions of the microprofile after pre-honing, as well as rolling the final treated surface.



The question arises, is it possible to obtain approximately the same surface immediately in the grinding process without any additional refinement? That is, is it possible to make a wheel at once to obtain a treated surface with "pockets"?

Our research has shown that this is possible, but for this we need to use a mixture of abrasives in the working layer. Thus, in [8] we once paid attention to the features of the tool with SHM, when the working layer of the wheel combines two or three grinding powders of different abrasives (diamonds and CBN), namely, additionally introduced into the working layer grinding powder compacts based on cubonite micropowders.

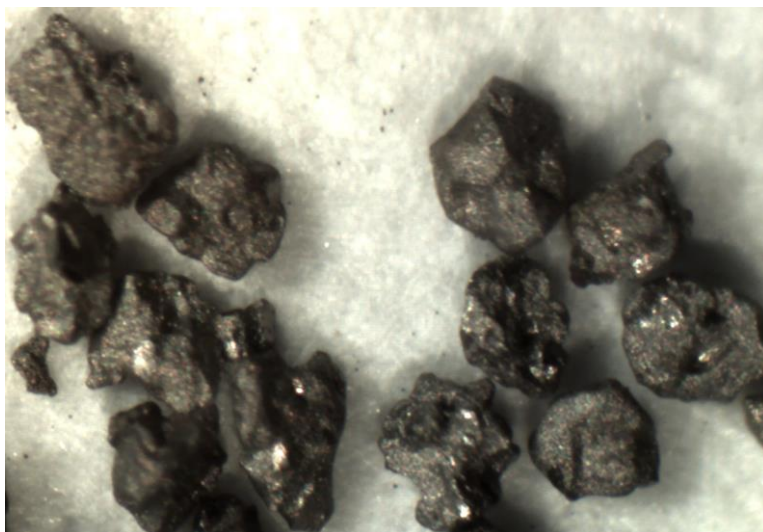


Figure 2 – General view of metallized grinding powders of compacts with grain size KM 400/315 from cubonite micropowders

These compacts have certain abrasive properties [8]. However, it should be noted that, probably due to the somewhat unusual (layered) wear of the grains of compacts, it is possible to form the original heterogeneous, unusual for the tradition. These wheels with SHM, the profile of micro-irregularities of the treated surface with the presence of peculiar "pockets" on the treated surface. However, attention was drawn to the fact that the above pure compacts are to some extent relatively "soft" and it was suggested that such compacts should be made more rigid due to their metallization (Fig. 2).

As the use of a mixture of grinding powders gives a certain effect, at the last stage for comparison the operational indicators of wheels were studied, when they use a mixture of KM compacts of different grain size and standard diamond grains

of corresponding grain sizes. The surface roughness was investigated when using wheels with a mixture in the ratio of 50 to 50 grains from compacts with a grain size of KM 400/315 and the corresponding diamond grains of the AC32 brand. Thus, there is a situation that now only 50% of compacts are in the working layer, and the other 50% are diamonds, which on high-speed steel have a wear mechanism close to compacts, because on them Wear planes are also formed, and this is observed by the nature of micro-irregularities of the treated surface (Fig. 3).

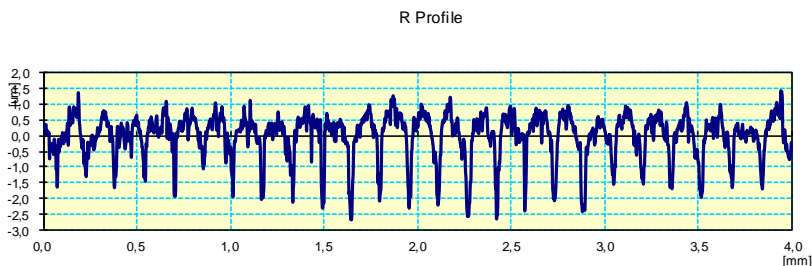


Figure 3 – The profile of microroughnesses of the processed surface in a wheel with a mix of grinding powders of the KM 400/315 compact and AC32 400/315 diamond

SUMMARY

Our research has shown that the ratio of roughness R_{max}/R_a is important to assess the distribution of the processing material in the rough layer, and thus to assess the possibility of forming a specific rough layer.

It is established that the simultaneous use of compacts and diamond grains in grain wheels may not improve the situation both in terms of wear resistance of the wheels and the quality of the treated surface, as it is impossible to achieve productive conditions for processing of high-speed steel. At the same time, it was found that with such a mixture in wheels it is possible to achieve a reduction in the roughness of the treated surface and the specific profile of micro-irregularities, when the so-called "oil pockets" are formed. That is, from the above it is clear that there is a real opportunity to implement in one wheels the conditions for obtaining a specific profile of micro-irregularities during grinding, when the so-called "oil pockets" are formed without any additional technological means.

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Валерій Лаврінєнко, Київ, Україна,
Володимир Солод, Кам'янське, Україна

СПІВІДНОШЕННЯ МІЖ ПАРАМЕТРАМИ ШОРСТКОСТІ І ОСОБЛИВОСТІ ФОРМУВАННЯ ПОВЕРХНІ ІЗ СПЕЦІАЛЬНИМ МІКРОПРОФІЛЕМ

Анотація. Викладені особливості зв'язку між основними висотними параметрами шорсткості R_{\max} та R_a , а також між кроковим St та висотним параметрами R_a при торцевому шліфуванні кругами з НТМ. Побудує такий досить стійкий міф, що вказані вище параметри як би незалежно існують самі по собі і можливо отримати будь-яке необхідне значення одного параметра і будь-яке бажане значення іншого, або, наприклад, можна подіяти на один параметр, а інші не зміняться. Наслідком такого міфу є те, що дослідники окремо вивчають вплив режимів і умов обробки на конкретні параметри шорсткості, чим вноситься системна похибка, оскільки насправді для однакових умов обробки всі параметри шорсткості пов'язані між собою і впливати тільки на один параметр є неможливим, бо зміняться і інші. Тому метою даної роботи було показати як змінюється співвідношення між основними висотними показниками шорсткості R_{\max} та R_a і як це може дозволити досягти умов формування поверхні із спеціальним мікропрофілем при алмазній обробці. Показано, що вказаний зв'язок між вказаними параметрами шорсткості в цілому зводиться до простих відношень. Наприклад, для спеченої і необробленої поверхні твердих сплавів таке відношення близьке до вигляду $R_{\max}/R_a \approx 4$. При лезовій обробці сталей різцями з Гексаніту-Р відношення R_{\max}/R_a вже є ≈ 6 . В цілому, ймовірно більш вірним було би вважати, що для абразивної обробки (в достатньо широкій області) відношення R_{\max}/R_a є більш близьким до вигляду $R_{\max}/R_a \approx (6-8)$, причому більші значення є характерними і для чистових методів абразивної обробки. А ось при доведенні кераміки і покриттів це відношення зростає до ≈ 10 . В останньому випадку свій внесок у відносно підвищення значення R_{\max} вносить пористість даних матеріалів, оскільки при доведенні вона

вже має значення. Наведене вище дозволило нам сформулювати таке положення: чим більша грубою є поверхня, тим вона має менше відношення між R_{max}/R_a , а чим більша довершеною є поверхня, отримана доведенням, поліруванням або іншими фінішними методами, тим це відношення є більшим. Тобто, наприклад, спечена поверхня і поверхня після абразивної обробки звичайними абразивами має відношення в діапазоні $R_{max}/R_a \approx (4-6)$. Обробка шліфувальними кругами з НТМ, коли поверхня має меншу шорсткість, аніж після наведених вище методів, і при тонкому шліфуванні переважно характеризується зростанням відношення до ≈ 8 . У випадку доводочних операцій на пористих матеріалах, коли значення R_a є невеликими, це відношення є вже близьким до $R_{max}/R_a \approx 10$. Як раз в цьому випадку дефекти самої обробленої поверхні у вигляді пор або подряпин і є причиною підвищення величини даного відношення. Між тим, низка подальших досліджень засвідчила, що такий висновок є неповним, оскільки відбиває тільки першу частину вказаної тенденції. Виявляється, що якщо нам необхідно отримати ще більшу довершену поверхню після шліфування, наприклад, поліруванням з отриманням значення величин шорсткості до 5–10 нм, тобто витрати на процес отримання поверхні зростають, то величина відношення R_{max}/R_a починає знижуватися і досягає тієї ситуації, коли вказане вище відношення стає близьким к вигляду $R_{max}/R_a \approx 4$. Тобто у нас відбувається своєрідна «дуга відношення висотних параметрів». Наведені дослідження дозволили виявити умови формування спеціального мікропрофіля оброблюваної поверхні при алмазному шліфуванні. Так, одночасне застосування в кругах зерен компактів і алмазних зерен ситуацію може не поліпшувати як з точки зору зносостійкості кругів так і якості обробленої поверхні, оскільки є неможливим досягти умов продуктивної безрипальної обробки швидкорізальної сталі. Разом з тим, виявлено, що саме при такій суміші в кругах і є можливим досягти зниження шорсткості обробленої поверхні і того специфічного профілю мікронерівностей, коли утворюються так звані „масляні кишені”. Тобто встановлено, що є реальна можливість реалізувати в одному кругу умови отримання при шліфуванні специфічного специфічного профілю мікронерівностей, коли утворюються так звані „масляні кишені” без будь-яких додаткових технологічних засобів.

Ключові слова: параметри шорсткості; співвідношення між висотними параметрами R_{max}/R_a ; спеціальний мікропрофіль.