Surface quality of high-speed cutting plates in flat grinding by new abrasive wheels of “Saint-Gobain Abrasive” company

Nguyen Duy Canh¹, Nguyen Van Canh¹*, Pham Xuan Hong¹, Nguyen Ngoc Hue² and Tran Dinh Duy¹

¹Ngo Quyen University, 229B, Bach Dang st., Binh Duong, 75153, Viet Nam
²Thu Dau Mot University, 6, Tran Van On st., Binh Duong, 75151, Viet Nam

Abstract. The article detected the surface qualities of high-speed plates – HS10-4-3-10; HS6-5-1; HS18-0-1; W12V3Co10Mo3 and W9Co5 at flat grinding by news abrasive wheels of company “Saint-Gobain Abrasive” – 5NQ46IVS3; 5SG46K12VXP, 5SG46I12VXP, 5SG60K12VXP, TGX80I12VCF5 with using statistical approach. Parameters of surface quality were estimated allowing: microrelief Ra and Sm; form accuracy FLTt and microhardness HV. Because of violation of the condition of homogeneity and normal distribution of variance deviations, nonparametric statistical method was selected for analysis experimental data. According by results of research were recommended using abrasive wheels: 5NQ46IVS3 and 5SG46K12VXP for the formation of parameters Ra, FLTt, HV; and abrasive wheels 5SG46I12VXP and 5SG60K12VXP for the provision parameter Sm.

1. Introduction

In the short-term, grinding technology trends will determine high standards of quality and effectiveness of treatment of products. Their implementation involves the development of a grinding tool with the technological characteristics of the process, equipment capabilities and properties of the processed material. In recent years, company “Saint-Gobain Abrasive” has manufactured new abrasive materials and a highly effective tool based on it: sol-gel abrasives - 3SG, 5SG, TG2, TGX2 and quantum abrasives - 3NQ, 5NQ [1-5]. The main feature of the new abrasive materials is ceramic alumina obtained by sintering of grain which consists of submicron particles (their sizes are 0.1 - 0.5 \( \mu \)m) with the formation of new multiple sharp cutting edges without flat wear pads and a unique combination of cutting ceramics and special organic ligaments [3-5]. All of the above contributes to increase the durability of grinding wheels and the accuracy of processing, reduce the height of the roughness of the machined surface and the frequency of dressing of the wheels and, ultimately, increase productivity. The new abrasive tools have permanent sharp cutting edges which are good to help heat generation, cutting forces and ensured the absence of burns, even with intensive grinding conditions [1]. Additionally, furthermore these wheels can increase the feed rate for cutting and, most importantly, the removal rate per pass without compromising the quality of processing [3], long service life [4], high strength and wear resistance of a tool with high productivity and accuracy to process a wide range of materials - from cast iron to nickel alloys [1-5].

Tools made of high-speed steels occupy a significant amount in the tool market, due to a lot of operational properties of materials [6]. In the manufacture of high-speed cutting tools flat grinding
methods are applied in the final operations which are carried out by grinding wheels. In designing of the grinding operations, the choice of an abrasive tool on which according to many output parameters (roughness, shape accuracy, microhardness) occupies an important role. At the same moment, the nomenclature of abrasive tools offered by manufacturers is extremely wide. In connection with reason, the task arises the selection of abrasive tools for processing of high-speed steels which are provided the best treatment and control conditions [1-3].

This work is devoted to the possibility of using statistical methods for evaluating the surface quality of high-speed flat plates and predicting the effect of the characteristics of new abrasive wheels “Saint-Gobain Abrasive” company for increasing of the efficiency of grinding process.

2. Materials and method of research

2.1. Experiment
The experiments were conducted by the periphery of abrasive wheels and the removal of the operating allowance corresponded to a pendulum scheme without standard grooming at the end of the grinding cycle. Following conditions were adopted:

- Surface grinding machine 3G71M, cutting fluids – 5% lubrication of emulsion Akvol-6 (Russian Technical Conditions TY 0258-024-00148845-98) with speed of flow 7-10 l/min
- The subject of experiment – cylinder high-speed plates 1; 5
  • 1–HS10-4-3-10 (HVinitial=7200 MPa); 2–HS6-5-2 (HVin.=6740 MPa); 3–HS18-0-1 (HVin.=7185 MPa); 4–W9Co5 (Р9К5 by Russian State Standard GOST 19265-73 [7], (HVin.=7169 MPa)); 5 –W12V3Co10Mo3 (Р12Ф3К10М3 by Russian Technical Conditions TU 14-1-1686-76 [8], (HVin.=6450 MPa)). Chemical composition and different standard grade of these steels were showed in table 1 [6-9];
- The characteristic of abrasive wheels of “Saint-Gobain Abrasive” company (j = 1; 5) according by [10]: 1–5NQ46IVS3; 2-5SG46K12VXP, 3–5SG60K12VXP, 4–5SG46I12VXP, 5–TGX80I12VCF5;
- Technological condition: speed of wheel – vw=35 m/s, cutting deep t=0.015 mm, the operating allowance z=0.15 mm, longitudinal feed sl=7 m/min, cross-feed sc=1 mm/double stroke.

**Table 1.** Chemical composition of steels $i = 1; 5$ and steel-grade of different standards [6-8]

| Steel $i$ | Chemical composition of high-speed steels $i = 1; 5$ in % of weight by ISO 4957:2004, GOST 19265-73 and TU 14-1-1686-76 |
|-----------|-----------------------------------------------------------------------------------|
| 1         | C 1.20-1.35  Cr 3.8-4.5  W 9.0-11.0  Mo 3.0-4.0  V 3.2-3.7  Co 9.5-10.5 |
| 2         | C 0.80-0.88  Cr 3.8-4.5  W 5.9-6.7  Mo 4.7-5.2  V 1.7-2.1  Co ≤0.5 |
| 3         | C 0.73-0.83  Cr 3.8-4.5  W 17.2-18.7  Mo ≤1.0  V 1.1-1.2  Co ≤0.5 |
| 4         | C 0.90-1.00  Cr 3.8-4.4  W 9.0-10.0  Mo ≤1.0  V 2.3-2.7  Co 5.0-6.0 |
| 5         | C 1.20-1.30  Cr 3.5-4.0  W 12.0-13.0  Mo 2.5-3.0  V 2.3-2.7  Co 9.5-10.5 |

**Steel grades of high-speed steels according by different standards [9]**

| Steel $i$ | ISO 4957 | GOST 19265 | ASTM A600 | JIS 4403 | EN 10028-2 | SS14 |
|-----------|----------|------------|-----------|----------|------------|------|
| 1         | EU       | RUSSIA     | USA       | JAPAN    | ENGLISH    | SWEDEN |
| 2         | HS10-4-3-10 | P9M4K8     | T42       | SKH57    | 1.3207     | 2736 |
| 3         | HS6-5-2   | P6M5       | M2        | SKH51    | 1.3339     | 2722 |
| 4         | HS18-0-1  | P18        | T1        | SKH2     | 1.3355     | 2750 |
| 5         | -         | P9K5       | T12008    | -        | -          | -    |
Parameters of the surface quality of the high-speed plates were selected: the microroughness – \( R_{aij} \); mean width of profile elements of the assessed profile – \( S_{mij} \); peak-to-valley flatness deviation (form accuracy) – \( FLT_{ij} \) and microhardness \( HV_{ij} \). Characteristic of parameters and the method of their measurement are given in [11-16].

2.2. Statistical methods
The cutting abilities of abrasive wheels are considered variable values. For the interpretation of observations probability-theoretical approaches are used [17-18]. Reduction of the labor intensity of statistical computations is achieved by using of software products, in particular, Statistica 10. In forced of analysis of the experimental data:

\[
\left\{ \bar{y}_{ijv} \right\}, \ i = 1; 5, \ j = 1; 5, \ v = 1; 30,
\]

where \( v \) – number of measurement for each parameter. It is possible to lead with the involvement of parametric (average \( \bar{y}_{ij} \), standard deviations \( SD_{ij} \) and ranges \( R_{ij} = y_{max_{ij}} - y_{min_{ij}} \)) and nonparametric (median \( \tilde{y}_{ij} \) and quartile latitude \( QL_{ij} = |y_{0.75} - y_{0.25}| \)) statistical methods.

For the parametric method, it is necessary that all Eq. (1) possess the properties of homogeneity of variance deviation and normality of distributions. Otherwise, the exact criteria of this method lose their reliability and can lead to the adoption of incorrect statistical decisions. In a similar situation, it is more expedient to use ranking statisticians which are not related to any family of distributions and do not use its properties. The choice of statistical methods is described in [16, 19]. Throughout of this study, we confine ourselves to stating that the procedure for interpreting Eq. (1) has been reduced to one-stage as following: a one-dimensional variance analysis for detecting a significant difference between the levels of measures positions without their nominal search.

The cutting abilities of abrasive wheels \( j = 2; 5 \) according by the position measures relative to the basic wheel \( j = 1 \) is considered by one-dimensional frequency distribution [16-19]:

- **Parametric method**
  
  \[ k_{\alpha,ij} = \frac{\bar{y}_{ij}}{\bar{y}_{11}}, \ i, j = 2; 5 \]  

- **Non-parametric method**
  
  \[ k_{\mu,ij} = \frac{\tilde{y}_{ij}}{\tilde{y}_{11}}, \ i, j = 2; 5 \]

For estimation of the process stability was used following calculations [16-19]:

- **Parametric method**
  
  \[ k_{z1,ij} = \frac{SD_{ij}}{SD_{1}}, \ i, j = 2; 5 \]  

  \[ k_{z2,ij} = \frac{R_{11}}{R_{ij}}, \ i, j = 2; 5 \]

- **Non-parametric method**
  
  \[ k_{z3,ij} = \frac{QL_{11}}{QL_{ij}}, \ i, j = 2; 5 \]

In Eq.4 – Eq.6, if \( k_{z1} > 1 \) there are predicted the process stability which is decreased and otherwise increased.

3. Results and Discussions
In the first, for selecting the method of statistical analysis of experimental data (1) were checked to procure the homogeneity of variance deviation and normal distribution with the acceptance of null-hypotheses \( H_0 \) and their rejection \( H_1 \) (alternative hypothesis). Verification of \( H_0 \) with the help three criteria: Levene, Brown-Forsythe and Cochran tests. The results of these test were showed in table 2.
It is clear that:

- For steel HS10-4-3-10 and Р9К5, Ho was rejected with respect to parameter Ra and Sm;
- For steel HS6-5-1, Ho was accepted for parameter Ra, FLTt and HV;
- For steel HS18-0-1, Ho was verified for parameter Ra and HV;
- For steel Р12Ф3К10М3, Ho was cancelled only with a parameter Ra.

Table 2. Test of homogeneity for the studied parameters of surface quality of high-speed plates  

| Parameter     | Marked effects are significant at p < 0.05 | Acceptation Ho |
|---------------|--------------------------------------------|----------------|
|               | Levene test                                | Brown-Forsythe test | Cochran test |
| HS10-4-3-10 (i=1) | 0.418                                      | 0.723           | 0.017        | No             |
| Ra            | 0.040                                      | 0.149           | 0.255        | No             |
| Sm            | 0.000                                      | 0.002           | 0.000        | Yes            |
| FLTt          | 0.001                                      | 0.032           | 0.000        | Yes            |
| HV            |                                           |                 |             |                |
| HS6-5-2 (i=2)  | 0.002                                      | 0.008           | 0.000        | Yes            |
| Ra            | 0.003                                      | 0.058           | 0.142        | No             |
| Sm            | 0.000                                      | 0.001           | 0.000        | Yes            |
| FLTt          | 0.002                                      | 0.004           | 0.000        | Yes            |
| HV            |                                           |                 |             |                |
| HS18-0-1 (i=3) | 0.008                                      | 0.045           | 0.013        | Yes            |
| Ra            | 0.148                                      | 0.330           | 0.093        | No             |
| Sm            | 0.854                                      | 0.902           | 0.012        | No             |
| FLTt          | 0.000                                      | 0.000           | 0.000        | Yes            |
| HV            |                                           |                 |             |                |
| P9K5 (i=4)    | 0.012                                      | 0.104           | 0.000        | Yes            |
| Ra            | 0.000                                      | 0.004           | 0.000        | Yes            |
| Sm            | 0.012                                      | 0.112           | 0.000        | No             |
| FLTt          | 0.060                                      | 0.136           | 0.000        | No             |
| HV            |                                           |                 |             |                |
| P12Ф3К10М3 (i=5) | 0.355                                      | 0.436           | 0.000        | No             |
| Ra            | 0.003                                      | 0.010           | 0.000        | Yes            |
| Sm            | 0.005                                      | 0.030           | 0.002        | Yes            |
| FLTt          | 0.016                                      | 0.037           | 0.000        | Yes            |
| HV            |                                           |                 |             |                |

The second stage, normal distribution of experimental data (1) was checked by the Shapiro-Wilk test which marked effects are significant at $\alpha > 0.5$. Results of Shapiro-Wilk test were showed in table 3. While grinding of high-speed steels HS10-4-3-10 and P12Ф3К10М3 normal distributions Ho were confirmed only one case for the parameter HV13 with $\alpha=0.512$ and HV54 with $\alpha=0.932$. For high-speed steels HS6-5-2 and HS18-0-1, Ho verified in three cases as follows: FLTt25 ($\alpha=0.853$), HV21 ($\alpha=0.903$), HV24 ($\alpha=0.621$) and Sm34 ($\alpha=0.897$), HV31 ($\alpha=0.818$), HV34 ($\alpha=0.961$). In the end, for plates P9K5, Ho accepted in 5 cases: Ra42 ($0.983$), Ra45 ($0.887$), Sm44 ($0.640$), Sm45 ($0.586$) and HV45 ($\alpha=0.636$).

Parametric method of statistic is used when experimental data Eq. (1) must satisfy homogeneity of variance deviation and distribution normality. From above analysis on homogeneity and normal distribution of observations (1) which was marked that Ho rejected in the most cases. Consequently, it is concluded that statistical nonparametric method is used for the analysis database of experiment, i.e. will use parameter medians $\tilde{y}_{ij}$ and Eq. (3) for estimation of cutting abilities of abrasive wheels and parameter quartile latitude $QL_{ij}=|y_{0.75}-y_{0.25}|$ and Eq. (6) for estimation of the process stability.
Table 3. Results of test of distribution normality of observations (1)

| Wheel          | Marked effects are significant at $\alpha_{ij} > 0.5$ |
|---------------|--------------------------------------------------|
|               | $R_{ij}$ | $S_{mij}$ | $F_{Lij}$ | $H_{ij}$ | $R_{ij}$ | $S_{mij}$ | $F_{Lij}$ | $H_{ij}$ |
| HS10-4-3-10 (i=1) | 0.093 (-) | 0.000 (-) | 0.080 (-) | 0.154 (-) | 0.049 (-) | 0.003 (-) | 0.026 (-) | 0.903 (+) |
| HS6-5-2 (i=2) | 0.467 (-) | 0.056 (-) | 0.138 (-) | 0.249 (-) | 0.067 (-) | 0.000 (-) | 0.014 (-) | 0.175 (-) |
| HS18-0-1 (i=3) | 0.001 (-) | 0.000 (-) | 0.015 (-) | 0.512 (+) | 0.030 (-) | 0.305 (-) | 0.008 (-) | 0.205 (-) |
| P9K5 (i=4) | 0.043 (-) | 0.015 (-) | 0.004 (-) | 0.031 (-) | 0.002 (-) | 0.000 (-) | 0.035 (-) | 0.621 (+) |
| P12Ф3К10М3 (i=5) | 0.101 (-) | 0.093 (-) | 0.002 (-) | 0.008 (-) | 0.024 (-) | 0.000 (-) | 0.853 (+) | 0.122 (-) |

Note: Signs in the bracket (-) rejected $H_0$ on normal distribution and (+) accepted $H_0$

In table 4 was showed results of estimation of cutting ability of abrasive wheels $i = 1; 5$ with using parameter medians $\tilde{y}_{ij}$ and Eq. (3) for each high-speed plates $i = 1; 5$:

- Parameter $R_a$ of high-speed plates $i = 1; 5$ is in range $0.034-0.075$ $\mu$m, i.e. lies in grade numbers N2-N3 according by ISO 1302:2002. From table 4, results of experiment were showed that while grinding of high-speed plates $i = 1; 5$ recommends using abrasive wheels $j = 1; 2$. They reveal the highest cutting ability in all of cases by measures of the position: grinding steels $i = 1; 5$ – in grade number N2 and for steels $i = 2-4$ – $R_a$ are smallest. Addition, when grinding plates HS10-4-3-10 ($i = 1$) and P12Ф3К10М3 ($i = 5$), abrasive wheel 5SG46I12VXP ($j = 4$) similarly was showed high cutting ability and can used to grinding of these steels. In the final, the best wheels for formation of parameter $R_a$ for each steel were shown that while grinding of high-speed plates $i = 1; 5$ recommends using abrasive wheels $j = 1; 2$. They reveal the highest cutting ability in all of cases by measures of the position: grinding steels $i = 1; 5$ – in grade number N2 and for steels $i = 2-4$ – $R_a$ are smallest. Addition, when grinding plates HS10-4-3-10 ($i = 1$) and P12Ф3К10М3 ($i = 5$), abrasive wheel 5SG46I12VXP ($j = 4$) similarly was showed high cutting ability and can used to grinding of these steels. In the final, the best wheels for formation of parameter $R_a$ for each steel were called: HS10-4-3-10 – $j = 2$; HS6-5-2 – $j = 1$; HS18-0-1 – $j = 2$; P9K5 – $j = 2$ and P12Ф3К10М3 – $j = 1$.

- Formation of mean width of the profile element $S_m$ was predicted in the range $48.23$ to $81.59$ $\mu$m. Parameter $S_m$ influence on operational properties of machine parts as follows: corrosion resistance, wear resistance, strength and fatigue strength of parts. The smaller $S_m$, the better the provision of these properties of mechanical parts. From this position, for increasing parameter $S_m$, abrasive wheels were selected: 5SG46I12VXP ($j = 4$) for steel HS10-4-3-10 ($i = 1$); 5NQ46I12V3 ($j = 1$) and 5SG46K12VXP ($j = 2$) for steel HS6-5-2 ($i = 2$); 5NQ46I12V3 ($j = 1$) for steel HS18-0-1 ($i = 3$); 5SG60K12VXP ($j = 3$) for steel P9K5 ($i = 4$) and wheel 5SG60K12VXP ($j = 3$) for steel P12Ф3К10М3 $i = 5$.

- Surface flatness deviations ($F_{Lt}$ - peak-to-valley flatness deviation) [14-18] affects the distribution of the peaks or bearing area of steels HS10-4-3-10 and P12Ф3К10М3 particle are the same and form in the range $14$ to $18$ $\mu$m with coefficients $k_{m,ij}, k_{n,ij}$ were varied at the diapason $0.93-1.20$ and $1.00-1.13$. Abrasive wheel $j = 5$ do not recommended for grinding of
these steels by criterion flatness deviations in comparison with the other wheels. Analogous results were showed wheel 5SG60K12VXP (j=3) for steels i=1, 5 and wheel 5SG46K12VXP (j=2) for steels i=2, 3. From data on table 4, optimal wheels for formation of surface flatness deviation taking into account the smallest of their value as for as: wheels j=4, 1, 2 for steel HS10-4-3-10 and P12Φ3K10M3; j=1, 4, 3 – HS6-5-2 and HS18-0-1; j=1 – P9K5.

- For the production of good quality parts have to ensure that heat-treated, desired microstructure, hardness, microhardness...[18]. In particular, in this study, microhardness of cutting plates after grinding must be greater initial. From this position, abrasive wheels were selected: \( j = \bar{1}; 4 \) - for plate HS10-4-3-10; \( j = 2 \) – for plate HS6-5-2; all experimental wheels \( j = \bar{1}; 5 \) - for plate HS18-0-1 and wheels \( j = 2, 5 \) – for plates P9K5 and P12Φ3K10M3.

Table 4. Measure of position (medians) and coefficient \( km_{ij} \) of high-speed cutting plates in flat grinding by abrasive wheels \( j = \bar{1}; 5 \)

| Parameter | Wheels \( j = \bar{1}; 5 \) | Materials \( i = \bar{1}; 5 \) and coefficient \( km_{ij} \) |
|-----------|------------------|---------------------|
| \( \bar{y}_{ij} \) | \( km_{ij} \) | \( \bar{y}_{ij} \) | \( km_{ij} \) | \( \bar{y}_{ij} \) | \( km_{ij} \) | \( \bar{y}_{ij} \) | \( km_{ij} \) |
| Ra\(_{ij}\), \( \mu \)m | 1 | 0.049 | 1.00 | 0.048 | 1.00 | 0.054 | 1.00 | 0.058 | 1.00 | 0.034 | 1.00 |
| 2 | 0.047 | 0.96 | 0.052 | 1.08 | 0.053 | 0.98 | 0.055 | 0.95 | 0.040 | 1.18 |
| 3 | 0.050 | 1.02 | 0.075 | 1.56 | 0.060 | 1.11 | 0.070 | 1.21 | 0.053 | 1.56 |
| 4 | 0.048 | 0.98 | 0.063 | 1.31 | 0.062 | 1.15 | 0.062 | 1.07 | 0.048 | 1.41 |
| 5 | 0.055 | 1.12 | 0.062 | 1.29 | 0.055 | 1.02 | 0.061 | 1.05 | 0.053 | 1.56 |
| Sm\(_{ij}\), \( \mu \)m | 1 | 64.07 | 1.00 | 50.39 | 1.00 | 50.80 | 1.00 | 70.55 | 1.00 | 56.77 | 1.00 |
| 2 | 62.04 | 0.97 | 49.94 | 0.99 | 60.54 | 1.19 | 61.91 | 0.88 | 64.66 | 1.14 |
| 3 | 51.51 | 0.80 | 52.54 | 1.04 | 65.07 | 1.28 | 53.96 | 0.76 | 53.75 | 0.95 |
| 4 | 48.23 | 0.75 | 60.55 | 1.20 | 65.98 | 1.30 | 56.55 | 0.80 | 49.92 | 0.88 |
| 5 | 73.25 | 1.14 | 56.29 | 1.12 | 55.97 | 1.10 | 75.99 | 1.08 | 81.59 | 1.44 |
| FLT\(_{i}\), \( \mu \)m | 1 | 15.00 | 1.00 | 13.00 | 1.00 | 12.00 | 1.00 | 15.00 | 1.00 | 15.00 | 1.00 |
| 2 | 15.00 | 1.00 | 17.00 | 1.31 | 16.50 | 1.38 | 19.00 | 1.23 | 15.00 | 1.00 |
| 3 | 18.00 | 1.20 | 15.00 | 1.15 | 14.00 | 1.17 | 18.00 | 1.20 | 17.00 | 1.13 |
| 4 | 14.00 | 0.93 | 14.50 | 1.12 | 13.00 | 1.08 | 17.00 | 1.13 | 15.50 | 1.03 |
| 5 | 16.00 | 1.07 | 19.00 | 1.46 | 17.00 | 1.42 | 21.00 | 1.40 | 17.00 | 1.13 |
| HV, MPa | 1 | 8896 | 1.00 | 6473 | 1.00 | 7638 | 1.00 | 6994 | 1.00 | 6314 | 1.00 |
| 2 | 7747 | 0.87 | 6951 | 1.07 | 7587 | 0.99 | 7537 | 1.08 | 7290 | 1.15 |
| 3 | 7919 | 0.89 | 4763 | 0.74 | 7919 | 1.04 | 5093 | 0.76 | 5557 | 0.88 |
| 4 | 8033 | 0.90 | 4983 | 0.77 | 8205 | 1.07 | 5093 | 0.76 | 5429 | 0.86 |
| 5 | 6003 | 0.67 | 5557 | 0.86 | 7537 | 0.99 | 7438 | 1.06 | 6777 | 1.07 |

Parameter \( QL_{ij} \) characterize the process stability. The smaller of the values of \( QL_{ij} \), the more stable of the process. Table 5 showed the measure of dispersion \( (QL_{ij}) \) and results of estimation of process stability (coefficient \( km_{ij} \) by \( QL_{ij} \)) of abrasive wheels \( j = \bar{1}; 5 \) for the plates \( i = \bar{1}; 5 \). By these results was selected abrasive wheels for each plate and parameter:

- \( QL_{ij} \) (Ra\(_{ij}\)): wheel 5SG46K12VXP (j=2) for grinding all materials with coefficient Eq.6 from 0.56 to 0.74. For each plate additional use abrasive wheel: HS10-4-3-10 – j=3, 4; HS6-5-2 and P9K5 – j=5; HS18-0-1 and P12Φ3K10M3 – j=4.
- \( QL_{ij} \) (Sm\(_{ij}\)): abrasive wheel 5SG46K12VXP (j=2) for plate HS10-4-3-10; abrasive tool 5SG60K12VXP (j=3) for plates HS6-5-2 and P9K5 and abrasive instruments 5NQ46IVS3 (j=1), 5SG46112VXP (j=4) for plates HS18-0-1 and P12Φ3K10M3.
QL\textsubscript{ij} (FLT\textsubscript{ij}): abrasive wheel 5NQ46IVS3 (j=1) detect to the best tool for grinding plates HS10-4-3-10 and HS6-5-2 when formation parameter FLTt also parameter QL. For plate HS18-0-1 was called abrasive instrument 5SG4612VXP (j=4). Abrasive wheels j=1, 2, 5 were showed the same process stability when grinding plate P9K5. In the end for grinding plate P12Φ3K10M3 revealed wheels 5NQ46IVS3 (j=1).

QL\textsubscript{ij} (HVij): According by measure of position (table 4), abrasive wheels j=4, 5 do not recommend to grinding materials i=2, 4, 5 at any value of QL\textsubscript{ij}. By measure of dispersion and level hardening of surface after grinding were selected abrasive wheels for each steel as following: j=4 – HS10-4-3-10; j=2 – HS6-5-2, HS18-0-1 and P12Φ3K10M3; j=1 – P9K5.

Table 5. Measure of dispersion (QL\textsubscript{ij}) and coefficients k$_{St.ij}$ of high-speed cutting plates in flat grinding by abrasive wheels \textit{j} = 1; 5

| Parameter | Wheels $j = 1; 5$ | Materials $i = 1; 5$ |
|-----------|------------------|---------------------|
|           | QL\textsubscript{ij} | k$_{St.ij}$ | QL\textsubscript{ij} | k$_{St.ij}$ | QL\textsubscript{ij} | k$_{St.ij}$ | QL\textsubscript{ij} | k$_{St.ij}$ | QL\textsubscript{ij} | k$_{St.ij}$ | QL\textsubscript{ij} | k$_{St.ij}$ |
| Raij, µm  | 1 0.023 1.00 | 0.025 1.00 | 0.016 1.00 | 0.026 1.00 | 0.021 1.00 |
| Smij, µm  | 1 20.84 1.00 | 17.92 1.00 | 17.46 1.00 | 28.89 1.00 | 15.74 1.00 |
| FLT\textsubscript{ij}, µm | 1 1.75 1.00 | 1.75 1.00 | 2.00 1.00 | 2.00 1.00 | 2.75 1.00 |
| HVij, MPa | 1 883 1.00 | 721 1.00 | 843 1.00 | 621 1.00 | 554 1.00 |

In terms of technologists when selecting abrasive wheels that must be simultaneously satisfy the good cutting ability and stability work, i.e. values of median ($\bar{\eta}_i$) and quartile latitude (QL\textsubscript{ij}) are smallest. From these positions for increasing the efficiency of the grinding process of high-speed cutting plates $i = 1; 5$ were called abrasive wheels as following:

- 5NQ46IVS3 (j=1) and 5SG46K12VXP (j=2) for formation parameter Ra.
- 5NQ46IVS3 (j=1) to provision parameters FLTt and HV. Additional recommended using abrasive wheel 5SG4612VXP (j=4) for grinding plates i=1, 4 with increasing of flatness deviation.
- For formation parameter Sm will be used 5SG4612VXP (j=4) for HS10-4-3-10; 5SG60K12VXP (j=3) for HS6-5-2 and P9K5; 5NQ46IVS3 (j=1) for HS18-0-1; 5SG4612VXP (j=4) for P12Φ3K10M3.
4. Conclusion

The nonparametric statistic, that is characterized median and quartile latitude, was selected for estimation of cutting ability of abrasive wheels and process stability.

Recommended abrasive wheels for improvement of surface quality of high-speed plates and process stability: 5NQ46IVS3 and 5SG46K12VXP for the formation of parameters Ra, FLTt, HV; and abrasive wheels 5SG46I12VXP and 5SG60K12VXP for the provision parameter Sm.

References

[1] Sachsel H G 2010 Precision Abrasive Grinding in the 21-st Century: Conventional, Ceramic, Semi Superabrasive and Superabrasive (Indiana: Xlibris Publishing)
[2] Jackson M J and Davim J P 2011 Machining with Abrasive (Berlin: Springer)
[3] Webster J and Tricard M 2004 CIRP Annals – Manufacturing Technology 54(2) 597-617
[4] Kiss S 2013 Key Engineering Materials 581 229-234
[5] Orlhac X., Jeevananthan M., Krause R. et al. 2007 Patent WO2007040865A1 PCT/US2006/033438. Abrasive tools having a permeable structure
[6] ISO 4957:2004 2004 Tool Steels (Geneva: International Organization for Standardization)
[7] GOST 19265-73 Bars and Strips of High-Speed Steel. Specification (Moscow: Russian State Standard)
[8] TU 14-1-1686-76 Bars from high-speed steel of the brand P12Φ3K10M3. Technical Conditions (Moscow: Russian Technical Condition)
[9] Database of Steel and Alloys. Scoure: http://www.splav-kharkov.com/choose_type_class.php?type_id=4
[10] Abrasive Technological Excellence. Norton Saint-Gobain, available at: https://pdfslide.net/documents/norton-catalogus.html
[11] ISO 4287-1997 Geometrical Product Specifications – Surface Texture: Profile method – Teams, Definitions and Surface Texture Parameters (Geneva: International Organization for Standardization)
[12] ISO 1302:2002 Geometrical Product Specifications – Indication of Surface Texture in Technical Product Documentation (Geneva: International Organization for Standardization)
[13] Calvo R, Gomez E and Domingo R 2014 International Journal of Precision Engineering and Manufacturing 15(1) 31-44
[14] Ilyas K M and Ma S Y 2014 Advanced Materials Research 941 2232-2238
[15] Ren M J, Cheung C F and Kong L B 2012 Measurement Science and Technology 23(5) 054005
[16] Soler Y I and Nguyen V C 2017 Journal of Engineering and Technological Sciences 49(3) 291-307
[17] Hollanoler M, Wolfe D A and Chicken E 2013 Nonparametric Statistical Methods (New York: Wiley)
[18] Wheeler D J and Chambers D S 2010 Understanding Statistical Process Control (Knoxville: SPC Press)
[19] Soler Y I and Nguyen V C 2017 Journal of Machinery Manufacture and Reliability 46(3) 279-287