Mathematical model of surface roughness at a flat grinding by periphery of a circle of metal-polymer parts

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Abstract. This scientific work focused on determination grinding modes for metal polymer products that are filled aluminium. Also it is necessary to ensure required surface roughness and the highest performance. We used three factor planned experiment to get equation surface roughness metal polymer product at a flat grinding. The analysis and processing the results of the experiment was performed using statistical methods. Preparation of the products for experiments based on previously obtained scientific data. We used only calibrated measuring instrument for taking readings. In this scientific work was obtained the equation of surface roughness and table feed and cut depth at flat grinding of metal polymer products. Also it’s been got values of grinding modes of metal polymer surfaces on the joint of the molding tool, according to required surface quality. An obtained curve was built. Comparisons with common relationships are made. The scope of the results has been determined. The values of grinding modes for processing metal polymer surface on the joint of the molding tool based on surface roughness also given in the scientific work.

1. Introduction
Modern technological development and competition set a goal for industry. This goal is a finding efficient production methods. Rapid development of science and technics, creation of composite materials allow find more efficient and cheaper ways and production technologies of the various details, machines and units to today’s engineering. Nowadays, application of metal polymer materials has found its use not only as a repair compound but as a construction material for the manufacture of machine parts. The authors proved opportunity of the shaping parts of the molding tools manufacture earlier [1] for small – quantity production of plastic metal polymer castings. This production method can significantly reduce the cost of production of the equipment as well as the cost of the products manufacture, using such equipment.

According to the GOST 27358 – 87 the surface roughness of the parting reference bases must correspond to the value of the Ra 0,80 microns, and flatness tolerance of plates reference bases and parting planes of the molding tools must correspond to the 6th degree of accuracy of the GOST 24643. The details surface quality is achieved by the operation of grinding on the final stage of processing. The physical processes during grinding, technology of grinding and its optimization during processing of steel products are described in scientific works of such scientists as V.A. Sipailov, S.S. Silin, S.N. Korchak, L.N. Philimonov [2, 3, 4, 5]. These scientists conducted extensive research, that concerned of steel details grinding processes, but application of existing patterns, namely assignment optimum
grinding modes for processing metal – polymer details will not be fair, because the structure, chemical and physical and mechanical properties of metal – polymers differ from the properties of the steels and iron alloys. An absence of the patterns for assignment grinding modes of the metal – polymer details of the molding tools doesn’t allow to process the metal – polymer surface on the joint of the molding tool subject to the required surface roughness. The assignment of the grinding modes for ensuring required quality of surface, (particularly the surface roughness) requires the definition of the grinding process model. The metal – polymer composition in production of the molding tools details is used as a material of the shape – generating plate. The final machining operation is a grinding of the parting reference bases. Therefore it is necessary to determine the parameters of the displacement table velocity Vtb and the cut depth t at which the surface roughness will correspond to the value of Ra = 0,8 microns.

Obtaining the required parameters of the surface roughness during processing by a flat grinding with the periphery of the wheel is also necessary at the detail recovery process using the metal – polymers [6].

2. Obtaining the dependence of the surface roughness of the metal – polymer product filled aluminium from the table feed and the cut depth at the flat grinding with the periphery of the wheel

In the research of the technological process of the grinding of the molding tool metal – polymer detail, the authors applied the technique with the construction of a planned experiment. This experiment is described in the [7], particularly, the three – factor experiment. As the variable parameters were selected: the table feed, the cut depth and the grinding wheel width. The metal – polymer samples were prepared taking into account the previous research. The studies have been described in the [8]. The curing modes of the metal – polymer composition significantly influence physical and mechanical properties of the cured metal – polymer material and, as a consequence, the result of the experiment.

The grinding of the samples was carried out on the flat surface grinder 3B722. The machine tool has a stepless speed regulation of the table movement. Therefore, the velocity of travel of the table was measured to obtain the upper, the lower and the basic numerical values of the velocity travel factor of the table. Marks were marked on the handle of the speed control throttle of the table displacement. A control mark was noted on the casing of the machine tool, and the table was marked with 0,1 m divisions. Then, using a digital camera the recording motion of the table was made at three rates of velocity. Then, the recalculating of the numerical value of the table speed to the m/min was carried out. The marking for calculation the table speed value is shown in Fig. 1.

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Figure 1. Marking of equipment for the numerical determination of the value of filing; a - on the housing and the machine table; b - on the handle throttle control filing.

Table 1 shows the obtained values of three rates of velocity of the table feed: the max, the min and the average, and the numerical parameters for the calculation.

| The position of the handle | The time of passage of a distance of 0,5 m, min | The feed table velocity, m/min |
|---------------------------|-----------------------------------------------|--------------------------------|
| Min                       | 0,05561                                       | 8,991                          |
| Average                   | 0,02722                                       | 18,369                         |
| Max                       | 0,01798                                       | 27,809                         |

The measurement of the surface roughness of the metal – polymer sample after the grinding was performed by the profilometer TIME TR 110. The measurement process is shown in Figure 2.

Figure 2. Measurement of the metal – polymer sample roughness by the profilometer TR110.

During the grinding it’s used three grinding wheels GOST 2424 – 83 diameter 450 mm, width of 32 mm, 40 mm, 50 mm, from the 25A material. The velocity of the wheel is 35 m/sec.

According to the experimental conditions, the table feed $V_{tb}$, m/min, the width of the wheel $B$, mm and the cut depth, m influence the surface roughness of the metal – polymer sample. The amount of the repeated tests during the experiment is accepted taking into account the recommendations [9].

To simplify the calculations used a lisenced commercial program PlanExp B – D13 v. 1.0. The software architecture is described in the [10]. The workspace window of the program is shown in the Figure 3.
Figure 3. Program working window PlanExp B-D13 v.1.0. (Russian interface)

The program allows to estimate the following polynomial form (1)

$$\bar{y} = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2$$

(1)

The factors, that define changing of the optimized parameters are recorded in a section 1. The factors and intervals of their variation are shown in the table 2.

Table 2. The factors and intervals of their variation.

| x1:  | 9  | 18,4 | 27,8 | 9,4   | the table feed                |
|-----|----|------|------|-------|-------------------------------|
| x2:  | 0,01 | 0,05 | 0,09 | 0,04 | the cut depth                 |
| x3:  | 30  | 40   | 50   | 10   | the wheel width               |

In the section 2 of the used program is described the plane of the experiment type B – D13, and the output parameters of the tests, the corresponding results are shown in the table 3.

Table 3. The plane of the experiment and the output parameters of the tests.

| № test (u) | The planning matrix | The actual values of the variables | The output parameter (Roughness) |
|------------|---------------------|-----------------------------------|---------------------------------|
|            | x1 x2 x2 x2        | the table feed the cut depth the wheel width | y(u, 1) y(u, 2) |
| 1          | -1 -1 -1           | 9 0,01 30 | 4,7 4,8              |
| 2          | +1 +1 -1           | 27,8 0,01 | 30 1,36 1,3           |
| 3          | -1 +1 -1           | 9 0,09 30 | 5,95 5,7             |
| 4          | -1 -1 +1           | 9 0,01 50 | 4,87 4,92            |
| 5          | -1 0,19 0,19       | 9 0,0576 | 41,9 3,61 3,58       |
| 6          | 0,19 -1 0,19      | 20,186 0,01 | 41,9 1,13 1,9        |
| 7          | 0,19 0,19 -1      | 20,186 0,0576 | 30 3,72 3,75        |
| 8          | -0,29 +1 +1       | 15,674 0,09 | 50 3,2 3,7           |
| 9          | +1 -0,29 +1       | 27,8 0,0384 | 50 2,42 2,2          |
| 10         | +1 +1 -0,29      | 27,8 0,09 37,1 | 2,06 2,1            |

The program automatically computes the coefficients of the mathematical model. The values of the coefficients are shown in the table 4.
Table 4. The equation coefficients of the mathematical model.

| $b_0$ | $b_1$ | $b_2$ | $b_3$ | $b_{11}$ | $b_{12}$ | $b_{13}$ | $b_{22}$ | $b_{23}$ | $b_{33}$ |
|-------|-------|-------|-------|----------|----------|----------|----------|----------|----------|
| 2,20  | -1,246| 0,40  | -0,249| 0,16     | 0,32     | 0,13     | -0,085   | -0,454   | 1,3      |
| 8     | 7     | 6     | 6      | 5        | 6        |          |          |          |          |

The calculated mathematical dependence model of the surface roughness at the flat grinding of the metal – polymers filled aluminium from the variable factors is as follows (2)

$$y = 2,208 - 1,246 \times x_1 + 0,407 \times x_2 - 0,249 \times x_3 + 0,326 \times x_1x_2 + 0,135 \times x_1x_3 - 0,454 \times x_2x_3 + 0,166 \times x_1^2 - 0,085 \times x_2^2 + 1,36 \times x_3^2$$  (2)

In the course of the experiment the measurement was taken in each tests in amount of two measurements. Therefore, the opportunity of the statistic processing data of the planned experiment exists.

It’s necessary to compare computational Student’s coefficient with the coefficient from the table to assess the significance of coefficients. In this experiment the variance of reproducibility in the parallel tests is 0,049, and the number of the degrees of freedom is 10, and the table value of the Student’s test is $t_{tb}=2,23$. The computational values of the Student’s test for each coefficient are shown in the table 5.

Table 5. The Student’s tests and the significance of the model coefficients (1/0 – significant/insignificant).

|       | $b_0$ | $b_1$ | $b_2$ | $b_3$ | $b_{11}$ | $b_{12}$ | $b_{13}$ | $b_{22}$ | $b_{23}$ | $b_{33}$ |
|-------|-------|-------|-------|-------|----------|----------|----------|----------|----------|----------|
| Student’s test | 10,74 | 14,165 | 4,62 | 7 | 2,83 | 0,97 | 3,10 | 1,28 | 0,5 | 4,32 | 7,99 |
| Significance | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |

The table shows, that the coefficients $b_{11}$, $b_{13}$, $b_{22}$ are insignificant for obtained model.

Verification of the math model adequacy is carried out according to the Fisher’s test, and the adequacy variance of the mathematical model is 0,163, the number of the degrees of freedom is 3 with significant coefficients. The table value of the Fisher’s test is $F_{table}=3,71$, this is less than computational value (computational value of the Fisher’s test is $F=3,33$). This means that the equation of the mathematical model is adequate according to the Fisher’s test. Model may be used to solve production tasks.

The Program Product PlanExp B – D13 v. 1.0. allows not only determine math model, but it can compute mathematical model with a fixation one of the variable factors.

Let’s calculate math model of the surface roughness of the metal – polymers filled aluminium in the flat grinding by a wheel 40 mm width, because this type of wheel is most often used in production. Thus, for the wheel $B = 40$ mm, math model will look like this (3)

$$y = 2,208 - 1,246 \times x_1 + 0,407 \times x_2 + 0,326 \times x_1x_2 + 0,166 \times x_1^2 - 0,085 \times x_2^2$$  (3)

Exclude insignificant coefficients and the model will take the form (4)

$$y = 2,208 - 1,246 \times x_1 + 0,407 \times x_2 + 0,326 \times x_1x_2$$  (4)

In the calculation of the factor plane, the values of the levels of the input factors are accepted in the coded form. Recalculation of the setpoints of the factors is done by a linear interpolation using the formula (5)

$$x_i = \frac{x_{iL} - x_{0i}}{\Delta x_i}$$  (5)
where $x_i$ – the value of the $i$-th factor in the coded form; $X_i$ – the value of the $i$-th factor in the actual form; $\Delta X_i$ – the interval of the variation of the $i$-th factor; $x_{0i}$ – the actual value of the base level of the $i$-th factor.

Changing the coded values of the levels of the input factors with the values in accordance to the equation (5), we obtain the following math model of the surface roughness of the metal – polymer filled aluminium in the flat grinding by the wheel with the width of 40 mm.

$$Ra(V_{tb}, t) = 2.208 - 1.246 \left( \frac{V_{tb}-18.4}{27.8-9} \right) + 0.407 \left( \frac{t-0.05}{0.09-0.01} \right) + 0.326 \left( \frac{V_{tb}-18.4}{27.8-9} \right) \left( \frac{t-0.05}{0.09-0.01} \right)$$ (6)

Having received the mathematical model of the dependence of the metal – polymer surface roughness on the cut depth and the table speed at flat grinding (6), we will set the interval of the table speed variation $V_{tb}=2..40$ m/min, and the cut depth $t=0.01..1$ mm. We formulate a graphic interpretation of the mathematical model (Figure 4), using mathematical package PTC MathCad Prime 3.1.

![Graphic interpretation of a mathematical model of roughness.](image)

**Figure 4.** Graphic interpretation of a mathematical model of roughness.

Using the decision block and the function “find” [12] in the PTC MathCad Prime 3.1 we calculate the values of the table speed and the cut depth at which the surface roughness of the metal – polymer detail will be equal 0.8 microns. Set the initial approximations for each parameters $V_{tb}=2$, $t=0.01$. Write the equation, the limitation and the function of the system. The list space PTC MathCad Prime 3.1 with the entered solution block is shown in the Figure 5.
Figure 5. Calculating the values of model variables to $Ra = 0.8$ micron.

The Figure 5 shows that the computational values of the table speed and the cut depth for the $Ra=0.8 \, \mu m$ are $V_{tb}=30.244 \, m/min$ and $t=0.01 \, mm$. The analysis of the graph (Figure 4) also shows, that the equation has 1 value for each required parameter, which satisfies the initial roughness value.

When processing structural, carbon and alloyed steel with a hardness of up to HRC 30 to achieve the roughness parameter of no higher than $Ra=0.8 \, \mu m$, according to the [11], it’s recommended to apply the following cutting conditions: the wheel speed is $V_{circle}=35 \, m/sec$; the machining allowance is $\Delta=0.3..0.35 \, mm$; the wheel cross – feed is $40\, mm$ $S_{cross}=10 \, mm/table feed$; the table feed is $V_{tb}=8 \, m/min$; the cut depth is $t=0.073$.

Comparing the obtained value of the table speed parameter for the metal – polymer with the recommended in the reference literature for the alloyed steel, we can conclude, that the performance of the metal – polymer detail processing less than performance of the alloyed steel processing because of the small cut depth. Thus, for the grinding the metal product with a length of 300 mm, a width of 35 mm and the machining allowance of 0.3 mm, required 11.25 sec of a technological time, and it’s required 18 sec to processing the metal – polymer product.

3. Conclusion

The obtained surface roughness model of the metal – polymer at flat grinding by a periphery of the wheel may be used for the assignment of the cutting conditions: the table speed and the cut depth, with the required surface roughness. In particular, in the flat grinding of the parting reference base of the metal – polymer detail of the molding tool, the surface roughness must be equal $Ra \, 0.8 \, \mu m$, the cut depth is $t=0.01 \, mm$, and $V_{tb}=30.244 \, m/min$, according to the GOST 27358 – 87. The comparing of the grinding parameters of the metal polymer detail and the alloyed steel detail, with the required surface roughness value shows that the processing the metal – polymer parting reference base is 6.75 sec longer than processing the alloyed steel detail. An increase of the metal – polymer detail [13] processing time will not affect the cost of the molding tool, because the molding tool is a single item. Significant cost reduction of the molding tool production using a metal – polymers repeatedly exceeds the increase of cost due to the increase of the technological time of the grinding of the parting reference base.

The results obtained during the research may be used in the plants engaged in plastics processing. Also the results can be used in the enterprises at the preparing of the design documentation on the metal – polymer products filled aluminum. Also the obtained model can be applied at the assignment of the processing modes in the flat grinding for the surfaces which repaired using the metal – polymer composition.
References

[1] Lubimyi N.S., Chepchurov M.S. Production of forming mold parts made of composite materials. Bulletin of the Siberian State Automobile and Highway Academy. v. 6, pp. 76–81. (2015)

[2] Sipailov V.A. Thermal processes in grinding and quality control in surface. (Moscow, Engineering Publ., 164 p. 1978)

[3] Silin S.S., Leonov B.N., Hrulkov V.A. et al. Optimization of technology of deep-grinding. (Moscow, Engineering Publ., 120 p., 1989)

[4] Korchak S.N. Performance of the process of grinding of steel parts. (Moscow, Engineering Publ., 280 p., 1974)

[5] Filimonov L.N. Surface grinding. (Leningrad, Engineering Publ., 108 p., 1985)

[6] Efremov V.V., Kutovoi S.S., Agoshkov A.V. The results of experimental studies on the management of quality indicators resurfacing parts in grinding. Bulletin of BSTU V.G. Shukhov. v. 9, pp. 131–136 (2016)

[7] Spiridonov A.A. An experiment in the study processes. (Moscow, Engineering Publ., 184 p., 1981)

[8] Lyubimyi N.S., Chepchurov M.S. The effect of applying vacuum during curing metallopolymers on its thermal conductivity. Proceedings of the All-Russia meeting of heads of departments of Materials Science and Technology of Materials “Interdisciplinary approaches in materials science and technology. Theory and practice”. Belgorod, BSTU V.G. Shukhova Publ., pp. 7–14 (2015)

[9] Boyko A.F. Kudenikov E.U. The exact method of calculation of the required number in the repeat experiment. Bulletin of BSTU V.G. Shukhov. v. 8, pp. 128–132 (2016)

[10] Belov V.V., Obraztsov I.V., Kuryatnikov Y.Y. Development of software and algorithmic data processing means of the planned three-factor experiment for the calculation of the mathematical model of concrete strength. Software products and systems Publ.. v. 108, pp. 254-259 (2014)

[11] Dalsky A.M., Suslov A.G., Kosilova A.G., Myascherikov R.K. Handbook technologist-mechanic (In 2 t. T. 2. Moscow, Engineering Publ., 944 p., 2003)

[12] Ochkov V.F. Mathcad Pro 7 for students and engineers. (Moscow, Computerpress Publ., 384 p., 1998)

[13] N.S. Lubimyi, M.S. Chepchurov, E.I. Evtushenko, V.P. Voronenko. Calculation of fixing element of metal-polymeric mold-forming surface of mold in metal cage. AIME Actual Issues of Mechanical Engineering. v. 133, - pp. 433-438 (2017).