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Effect of mass of parts on removal rate under vibroabrasive machining

V. I. Butenko, A. V. Stel'makh

Don State Technical University (Rostov-on-Don, Russian Federation)



Introduction. It should be noted that the study on the problem of the effect of the mass of parts on the vibration-abrasive processing is insufficient. In the works of A.P. Babichev and M.A. Tamarkin, the fact of such an effect is mentioned, but the degree and mechanism of the effect are not disclosed. In the metal removal formulas, only the number of interactions leading to microcutting is taken into account. The present work objective is to determine the effect of the mass of parts on the metal removal rate under vibroabrasive machining.

Materials and Methods. An empirical, i.e., experimental, approach is used. Parts from D16 and 30KhGSA materials which are widely used in the aviation industry were selected as samples. To change the mass, holes were drilled in the blanks; lead was poured into some samples, and plugs made of the same material as the blanks themselves were clogged into the others. Thus, experiments were carried out with solid, hollow, and weighted with lead samples. The working abrasive medium was scrap of grinding wheels of 40×80 mm, 25 grain size, and of trihedron prisms of 15×15 mm, 16 grain size. The experiments made it possible to clearly demonstrate the effect of grain size on the removal rate of the workpiece.

Results. The parameters of the effect of the mass of parts on the removal rate under vibroabrasive processing are determined. The results obtained show the removal per unit area. The data are approximated by the least squares method with a linear function. A version of its distribution is selected using the Fisher statistical criterion.

Discussion and Conclusion. It is shown how the workpiece mass determines the specific removal rate under the vibroabrasive machining. In the future, the database which is used to determine the effect of the work material characteristics on the process under consideration should be replenished. This will allow introducing a correction factor for the influence of mass in the metal removal formula, which will provide more accurate prediction of metal removal at the design stage of technological processes of vibration-abrasive machining.

Keywords: vibroabrasive machining, abrasive environment, finishing and clearing treatment, mass, specific removal rate, approximation, Fischer criterion, influence coefficient of weight, scrap of grinding wheels, grain size.

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Introduction. Engineering has always faced the task of improving the quality of its products. With advances in technology, ways of its solution are improved. This requires methods for predicting the efficiency of finishing processes. Vibroabrasive processing provides the required quality parameters along with high productivity, processing complex parts, as well as multiple-workpiece machining. In order to solve the issues under consideration, the following are being studied:

- organization and development of processes and methods of affecting the working abrasive medium and the object to be processed;
- development of new media and processing techniques;
- reduction of energy costs;
- improving the quality of processing [1].

During vibroabrasive treatment, metal and its oxides are removed from the surface due to mutual collisions of medium particles and workpieces. This process is provided through vibration of the working chamber, in which the workpieces and the medium are located. The camera is mounted on spring supports, so it can vibrate in various directions. Oscillations are transferred from an inertial (or other type) vibrator with a frequency of up to 50–100 Hz and an amplitude of 0.5–5.0 mm or more [2]. The number of interactions on a unit of surface of the workpiece per unit time is of random nature [3–10].

The study objective is to determine the effect of the mass of parts on the specific removal of metal under the vibroabrasive treatment.

Materials and Methods. The processing was carried out on a universal vibro-tumbling machine with four working chambers with a volume of 10 liters. The analytical balance AD 200 was used for mass measurements.

The working abrasive medium was scrap of grinding wheels of 40×80, grain size 25 [11] (Fig. 1), as well as trihedral prisms (TP) of 15×15 mm, grain size 16 (Fig. 2).



Fig. 1. Scrap of grinding wheels of 40×80, grain size 25



Fig. 2. Trihedral prisms, grain size 16

After a rough turning operation, the samples were processed in an environment of trihedral prisms for 10 minutes to remove burrs and smooth out roughness (Fig. 3).



Fig. 3. Processed parts from aluminum D16 and steel 30GSA

Then, processing was carried out in two stages of thirty minutes in the scrap of abrasive wheels. The working chamber vibrated with a frequency of 34.7 Hz and fluctuated with amplitude of 2.5 mm under continuous supply of process liquid (soda ash solution, 0.2%). The solution removed wear products (particles of metal and abrasive) from the surface of parts and the working medium. Then, processing was carried out in a TP medium (also in two stages of thirty minutes).

Research Results. As a result of the experiments, the desired values of mass m , g, and specific removal rate were obtained. Deviations of d from the theoretical model were estimated. The calculated and tabular values of the Fisher criterion were considered in comparison (Tables 1–4).

Table 1

Resulting data on mass and specific removal of samples from steel 30HGSA in TP environment

Weight, m , g	Removal rate, g/mm^2	d (deviation)
28.53175	2.18976E-06	-1.28317E-07
28.5348	1.73433E-06	-5.83836E-07
40.60125	2.8835E-06	2.10629E-07
40.6065	2.99742E-06	3.24395E-07
44.72755	2.98196E-06	1.87783E-07
44.73305	3.12387E-06	3.2954E-07
78.52885	3.29591E-06	-4.91895E-07
78.5414	4.01564E-06	2.27469E-07
96.7192	3.47528E-06	-8.4725E-07
96.48725	4.55972E-06	2.44012E-07
103.5209	4.14608E-06	-3.76394E-07
103.5378	5.42683E-06	9.03865E-07
Discrepancy	2.68051E-12	
Standard deviation	1.01462E-06	
Confidence interval 95 %	9.09679E-07	
Average	3.40253E-06	
Right class boundary	4.3122E-06	
Left class boundary	2.49285E-06	
F calculated	32.24585006	
F tabulated	3.105806516	
Angular coefficient a	2.93961E-08	
Free member b	1.47936E-06	

Table 2

Resulting data on mass and specific removal of samples from steel 30HGSA
in wheel-scrap environment

Weight, m , g	Removal rate, g/mm^2	d (deviation)
28.55685	3.41274E-06	2.74176E-08
28.5631	3.55469E-06	1.69061E-07
40.6304	3.99566E-06	1.37735E-08
40.6367	3.59643E-06	-3.85769E-07
44.7538	4.08941E-06	-9.6225E-08
44.7618	4.54399E-06	3.57958E-07
78.58825	6.05373E-06	1.96296E-07
78.6054	5.48683E-06	-3.71445E-07
96.5534	6.59611E-06	-1.49006E-07
96.775	6.5642E-06	-1.91866E-07
103.5847	7.8442E-06	7.51664E-07
103.6058	6.77172E-06	-3.21859E-07
Discrepancy	1.21985E-12	
Standard deviation	1.5276E-06	
Confidence interval 95 %	1.3696E-06	
Average	5.20914E-06	
Right class boundary	6.57874E-06	
Left class boundary	3.83954E-06	

Weight, m , g	Removal rate, g/mm^2	d (deviation)
F calculated	8.4308727	
F tabulated	3.105806516	
Angular coefficient a	4.94112E-08	
Free member b	1.97429E-06	

Table 3

Resulting data of mass and specific removal of samples from aluminum D16 in TP environment

Weight, m , g	Removal rate, g/mm^2	d (deviation)
10.13095	1.36343E-06	3.59001E-07
10.13305	1.19318E-06	1.88631E-07
14.59555	1.10785E-06	-1.5278E-07
14.59835	1.5057E-06	2.44909E-07
27.98755	1.00601E-06	-1.02312E-06
27.9912	1.1657E-06	-8.63641E-07
34.66113	1.83039E-06	-5.81706E-07
34.73845	4.14834E-06	1.73181E-06
60.9715	3.36435E-06	-5.57569E-07
60.98585	4.57721E-06	6.54468E-07
Discrepancy	6.11719E-12	
Standard deviation	1.36499E-06	
Confidence interval 95 %	1.40279E-06	
Average	2.12622E-06	
Right class boundary	3.529E-06	
Left class boundary	7.23431E-07	
F calculated	13.93008274	
F tabulated	3.249835542	
Angular coefficient a	5.73851E-08	
Free member b	4.23063E-07	

Table 4

Resulting data of mass and specific removal of samples from aluminum D16
in wheel-scrap environment

Weight, m , g	Removal rate, g/mm^2	d (deviation)
10.12275	3.18169E-06	8.85432E-07
10.1236	2.31113E-06	1.47567E-08
14.58795	3.63568E-06	7.25513E-07
14.5936	3.20988E-06	2.98936E-07
27.97185	3.54486E-06	-1.20542E-06
27.9844	4.00792E-06	-7.44089E-07
34.43015	4.09858E-06	-1.53964E-06
34.43015	6.08322E-06	4.45003E-07
60.92935	1.10349E-05	1.75338E-06
60.99307	8.65641E-06	-6.33871E-07
Discrepancy	9.45129E-12	
Standard deviation	2.79828E-06	
Confidence interval 95 %	2.87576E-06	
Average	4.97643E-06	
Right class boundary	7.85219E-06	
Left class boundary	2.10066E-06	
F calculated	51.65197229	
F tabulated	3.249835542	

Weight, m , g	Removal rate, g/mm^2	d (deviation)
Angular coefficient a	1.37487E-07	
Free member b	9.04509E-07	

We approximate the tabular data by a linear dependence using the least-squares method. We take the approximating function in the form: $y = ax + b$. Then the discrepancy (sum of squared deviations) has the form: $S(a, b) = \sum_{i=1}^n (y_i - ax_i - b)^2$. In the least-squares method, discrepancy should be minimal. At the minimum point of the multivariable function, the partial derivatives of this function with respect to independent parameters are equal to zero; therefore, the minimum conditions are:

$$\begin{cases} \frac{\partial S}{\partial a} = -2 \sum_{i=1}^n (y_i - ax_i - b)x_i = 0, \\ \frac{\partial S}{\partial b} = -2 \sum_{i=1}^n (y_i - ax_i - b) = 0. \end{cases}$$

After transformations, we obtain the following system of two algebraic equations with two unknowns:

$$\begin{cases} a \sum_{i=1}^n x_i^2 + b \sum_{i=1}^n x_i = \sum_{i=1}^n x_i y_i, \\ a \sum_{i=1}^n x_i + bn = \sum_{i=1}^n y_i. \end{cases}, \quad (1)$$

Denote the mass of parts by x , y is the specific removal of workpieces. We approximate the given tabular function by a linear dependence. To determine the best parameters a and b by the least-squares method, we solve the system (1). We solve the system using the matrix method in Microsoft Excel and obtain the values of a and b (see Tables 1–4).

To check the adequacy of the results, we use the Fisher criterion and tabulate them (see Tab. 1–4). The calculated value of the Fisher criterion has the form:

$$F_{\text{расчет.}} = \frac{\sum (y_i \text{ расчет.} - y_{\text{среднее расчет.}})^2}{t} \times \frac{n - t - 1}{\sum (y_i - y_i \text{ расчет.})^2},$$

where t is the number of factors x affecting y ; n is the number of observations.

Through comparing the calculated and tabulated values of the Fisher coefficient (see Tab. 1–4), we see that the calculated F significantly exceeds the tabulated F . Thus, we can conclude that the constructed dependence corresponds to the initial data with 95% confidence.

Substitute the obtained values of a and b .

For 30KhGSA samples in the TP environment, $y = 2.93961E - 08 \times x + 1.47936E - 06$, in the wheel-scrap environment, $y = 4.94112E - 08 \times x + 1.97429E - 06$.

For D16 samples in the TP environment, $y = 5.73851E - 08 \times x + 4.23063E - 07$, in the wheel-scrap environment, $y = 1.37487E - 07 \times x + 9.04509E - 07$.

Graphically, the results are presented in Fig. 4–7.

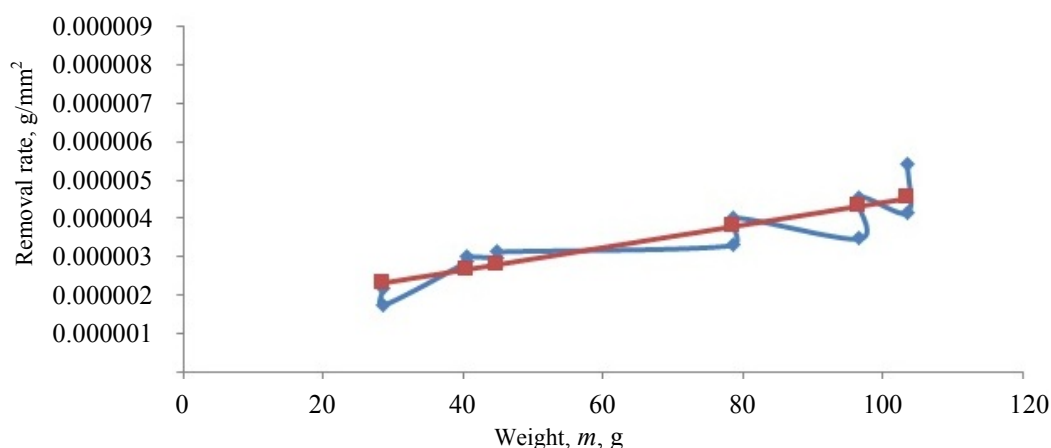


Fig. 4. Graph of dependence on specific removal mass of material of 30HGSA samples processed in TP

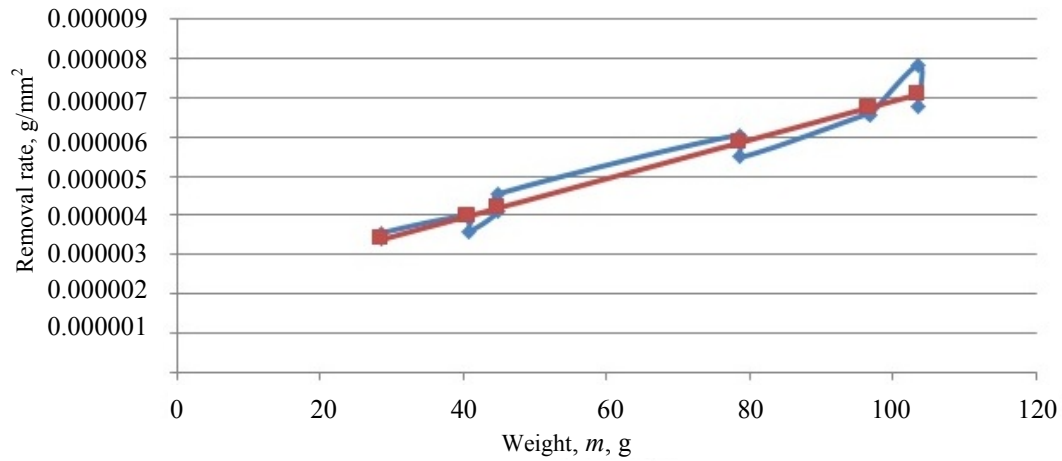


Fig. 5. Graph of dependence on specific removal mass of material of 30HGSA samples processed in wheel scrap

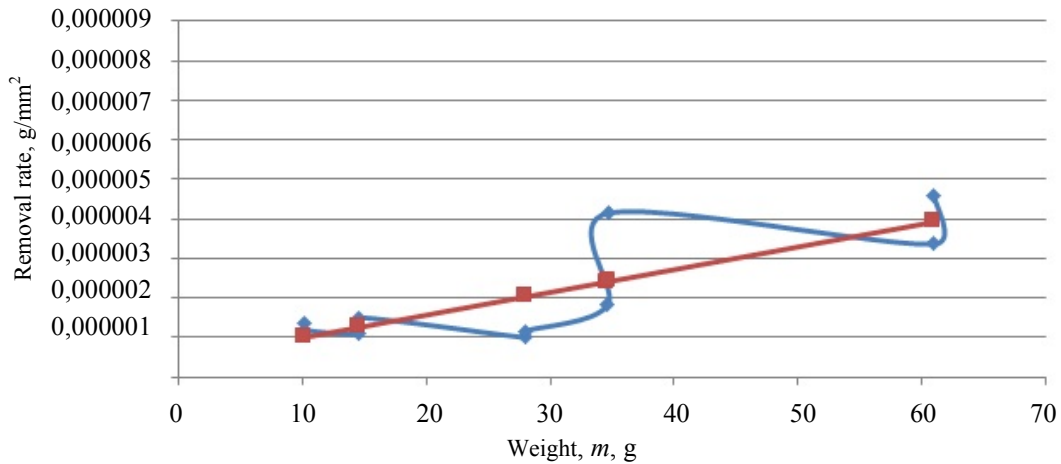


Fig. 6. Graph of dependence on specific removal mass of material of D 16 samples processed in TP

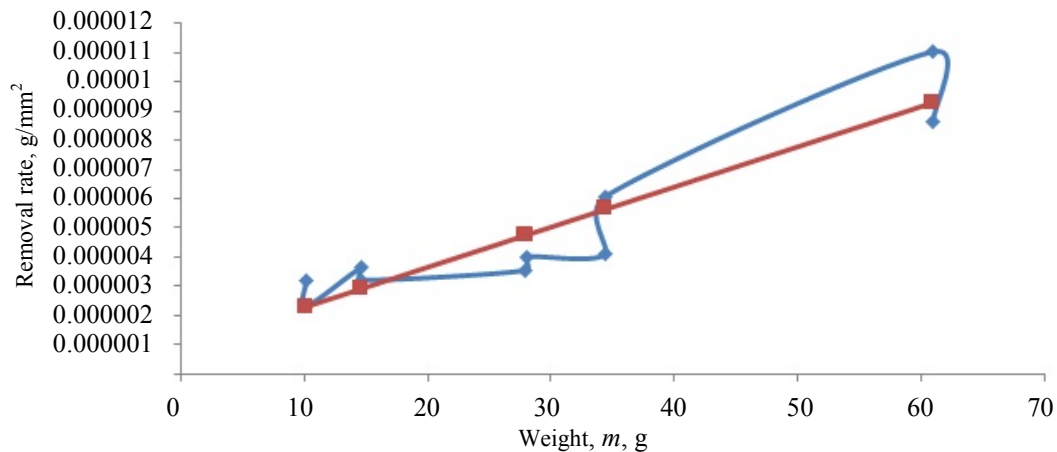


Fig. 7. Graph of dependence on specific removal mass of material of D 16 samples processed in wheel scrap

The graphs show that the specific removal rate varies significantly depending on the environment, as well as on the mass and material of the workpieces.

Conclusion. In analyzing Fig. 4–7, we can conclude that under machining workpieces of a larger mass, specific removal rate increases. This is due to changes in the momentum.

Since the momentum is equal to the product of the mass of the body and its speed, then with an increase in the mass of the workpiece, the momentum of the interaction of particles and the workpiece surface increases. With an increase in the mass of workpieces twofold, the specific removal rate increases by 1.5–2.2 times. When comparing the

values of the angular coefficient a and the free term b between treatments, we can assume that they are affected by the parameters of the graininess of the media, as well as the characteristics of the processed material. The results obtained allow us to verify the theoretical dependences through introducing a coefficient to determine the impact of mass ratios. This will provide more accurate prediction of removal at the design stage of the vibration-abrasive processing. The results obtained replenish the database, which is used to determine the effect of the work material characteristics and the environment on the process under consideration.

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About the authors:

Butenko, Viktor I., professor of the Engineering Technology Department, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Dr.Sci. (Eng.), professor, ScopusID [35972120700](https://orcid.org/0000-0001-9260-1030), ORCID: <https://orcid.org/0000-0001-9260-1030>, butenkoviktor@yandex.ru.

Stel'makh, Andrei V., graduate student of the Engineering Technology Department, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), ORCID: <https://orcid.org/0000-0002-8630-8748>, andreystelmakh91@mail.ru.

Claimed contributorship

V. I. Butenko: academic advising; analysis of the research results; the text revision; correction of the conclusions. A. V. Stel'makh: basic concept formulation, research objectives and tasks setting; computational analysis; text preparation; formulation of conclusions.

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