Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 150 (2016) 942 – 947

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2016

Rationalization of Polymer Composite Materials Processing by Improving Production Efficiency

A.S. Yanyushkin[a], D.A. Rychkov[a,*], D.V. Lobanov[a]

[a] *Bratsk State University, Makarenko st., 40, Bratsk 665709, Russia*

Abstract

Economic efficiency is one of the main criteria in the design of technological parts processing. To determine this criterion we have identified the main production expenses, including the cost of the cutting tool, the cost of its training, workers' wages, energy and materials costs. Cost values were obtained for different process parameters. The parameters of the process were the cutting conditions, structural and technological characteristics of cutting tools, as well as the properties of the material being processed. On the basis of the calculated data and the results of conducted experimental studies rationalization of process parameters was performed. It is possible to increase the economic efficiency of the machining of polymeric composite materials by the example of milling fiberglass. The research found that the dependence of the resulted expenses of the cutting conditions has an extreme character, where the minimum point shifted upward cutting conditions by increasing production. According to the research recommendations for the purpose of cutting conditions were developed, ensuring minimal production expenses.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of ICIE 2016

Keywords: economic efficiency; cutting conditions; polymer composite materials; resulted expenses

1. Introduction

Creation of new structural materials for the manufacture of parts for various technical purposes is an integral part of modern industry, because the requirements for the products are mainly aimed at reducing their weight, increase strength, retention of properties when exposed to aggressive environments and temperature without additional

* Corresponding author. Tel.: +7-904-119-2535; fax: +7-395-232-5360.
E-mail address: rychkovda@gmail.com

1877-7058 © 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of ICIE 2016
doi:10.1016/j.proeng.2016.07.067

production expenses. These requirements are satisfied polymer composites with fillers of high-strength fibers or fabrics. Products from polymers prepared by impregnating reinforcement fibers and fabrics with a polymeric binder, followed by compression, which requires additional machining [1-6]. However, the cutting tool wears rapidly and can't provide high-performance processing. This is due to the structure and properties of high-strength polymers with excipients which may vary during the machining operation and the influence of the cutting tool, the processing performance and surface quality [7-12]. The quality of the treated surfaces is not acceptable.

Improving the quality of the treated surfaces is possible by selection of rational parameters of the process of machining and design characteristics of the cutting tool. However, this requires many laboratory and theoretical studies, which often is not economically advantageous to produce. Current recommendations in the field of polymer processing, reinforced by high-strength components, to reduce the need for a cutting part as carbide and superhard materials [4, 7, 13]. However, it should take into account the specific geometry of the tool, which suggests the presence of increased cutting angles: front and rear. A problem arises in obtaining such a geometry of cutting elements made of high strength tool materials. When sharpening tool with a small tapering angle is impossible by conventional methods to provide the required quality of the cutting edge [14, 15]. One of the advanced technologies of processing of high-strength materials is diamond grinding simultaneously etched details and corrections wheel on metal bond [16-18]. The method allows to obtain high quality surfaces and cutting edges of the tool, it is necessary to ensure the efficiency of production of products from polymeric reinforced composite materials.

Nomenclature

C_t	tool costs, $
E	the total cost of processing a single cutting tool, $
E_{ch}	the cost to replace the cutters, $
E_{sh}	costs for sharpening of cutting tools, $
E_w	wages machinist, $
E_{pow}	power costs, $
E_M	material costs, $
n_i	the maximum number of indexable cutters
C_{cut}	the cost of one cutter, $
z	number of the cutters
τ_{sh}	time sharpening a cutter, min.
$C_{h.r}$	hourly rate machinist, $/h.
i	permissible number of sharpening cutters
T_c	total cutting tool life, min.
T	period resistance of the cutting tool, min.
N	average cutting power, kW
C_e	the cost of electricity, $/kW·h.
Q	the volume of material removed for the cutting tool life, mm^3
ρ	the density of the material being processed, kg/m^3
C_M	the cost of one kilogram of processed material, $/kg
R_e	resulted expenses, $/$mm^3$
P	continuous processing performance, mm^3/min.
l	the path traversed by the cutting tool during the period of resistance, mm
t	cutting depth, mm
b	milling width, mm
τ_a	auxiliary time to replace the cutting tool, min.
S_z	feed on the cutter tooth, mm/tooth
n	spindle speed, min^{-1}

Measures on the rationalization the process parameters don’t include the expenses that determine the cost-effectiveness of production [19, 20]. Thus, the actual problem is to increase the efficiency of processing of composite materials. To solve this problem we need to develop a methodology to assess the resulted expenses, taking into account design features of the instrument, its efficiency and cutting conditions that allow optimizing the production process.

2. The theoretical part of the study

The effectiveness of the technological processing represented by different criteria: quality, performance, reliability, stability, economy etc. The present study examined the cost-effectiveness as the main criterion in the design process. In determining this criterion, it is necessary to identify the costs of production. They include the costs of cutting tools, basic materials, equipment, workers' wages, energy costs and other expenses. A significant part of the cost amount to the cutting tool and service for the entire period of operation. It is worth noting that the cost-effective use of all kinds of tools, as it increases the variability of tool materials, and with the full wear of the cutting elements is sufficient to replace them with new ones. This modular tool body has a certain lifespan, which is regulated by the manufacturer.

Focusing on the cutting tool, it is possible to allocate the cost of processing parts for the period from the start of operation of the cutting tool assembly to its full production:

- The cost of modular tools.
- The cost to replace the cutting elements.
- Costs for sharpening tools.
- Wages machine operator.
- Energy costs.
- Material cost.

Thus, for each part of manufacturing operations production expenses can be calculated:

$$E = C_t + E_{ch} + E_{sh} + E_w + E_{pow} + E_M \quad (1)$$

$$E_{ch} = n_i C_{cut} z \quad (2)$$

$$E_{sh} = \tau_{sh} z \frac{C_{h.r}}{60} in_i \quad (3)$$

$$E_w = T_c \frac{C_{h.r}}{60} \quad (4)$$

In the present study, the cutting tool life is determined by the operation of the cutting tool starts its operation to completely deplete:

$$T_c = Tin_i \quad (5)$$

Power costs are calculated on the basis of power consumption for the entire life of the cutting tool, cutting with the average power is calculated empirically on the basis of three or more parts in the processing of the test on the test equipment:

$$E_{pow} = NT_c C_e \quad (6)$$

$$E_M = Q\rho \cdot C_M \cdot 10^{-9} \quad (7)$$

Substituting the expressions (2-7) in the formula (1), we obtain:

$$E = C_t + n_i C_{cut} z + \tau_{sh} z C_{h.r} in_i / 60 + Tin_i C_{h.r} / 60 + NTin_i C_e + Q\rho \cdot C_M \cdot 10^{-9} \quad (8)$$

To optimize the process used by the specific value of the production cost, reduced to the volume of material removed for the resource of cutting tools:

$$R_e = \frac{E}{Q} \quad (9)$$

$$Q = T_i P = Tin_i P \quad (10)$$

Substituting expression (8, 10) in the formula (9), we obtain:

$$R_e = \frac{C_t + n_i C_{cut} z + \tau_{sh} z C_{h.r} in_i / 60}{Tin_i P} + \frac{C_{h.r} / 60 + NC_e}{P} + \rho C_M \cdot 10^{-9} \quad (11)$$

The first term in the formula (11) characterizes the expenses of the cutting tool, the second – the cost of labor and the working energy, and the third – the cost of basic materials.

In the formula (11) the dependence of reduced costs by cutting conditions expressed implicitly. In order to establish a functional link explicitly express the continuous processing performance and period resistance of the cutting tool by cutting conditions.

Continuous processing performance while milling is determined by the formula:

$$P = \frac{ltb}{T + \tau_a} = \frac{TS_z zntb}{T + \tau_a} \quad (12)$$

With the increase in serial production are various tools and automation tools that reduce idle times. For a single production time τ_a will be the maximum, but for mass production - minimal. The period resistance of the cutting tool is determined by a function, which can be obtained as a result of experimental studies.

By varying the process parameters measured by the estimated value of the resulted expenses, which should be the minimum for optimal production conditions.

3. Results and Discussion

In order to rationalize the mode of cutting of composite materials to improve the economic efficiency of the production process carried out laboratory research period resistance of the cutting tool when machining fiberglass various tool materials. As a result, the mathematical models were obtained:

For VK8: $$T = 0{,}82 \cdot S_z^{4{,}75+2{,}94\ln S_z+2{,}38\ln t} \cdot t^{0{,}46+1{,}13\ln t} \quad (13)$$

For VK15: $$T = 0{,}66 \cdot S_z^{2{,}08+1{,}11\ln S_z+3{,}02\ln t} \cdot t^{2{,}54+0{,}65\ln t} \quad (14)$$

For VK3M: $$T = 0{,}64 \cdot S_z^{3{,}49+2{,}42\ln S_z+3{,}44\ln t} \cdot t^{2{,}05+1{,}04\ln t} \quad (15)$$

On the basis of the calculated and experimental data obtained plots of resulted expenses by cutting conditions (Fig. 1, 2). Increasing the feed per tooth at a constant depth of cut (Fig. 1) leads to uniform growth resulted expenses until the feed per tooth of the order of 0.25 mm/tooth, followed by a sharp increase. With the increase in serial production of these dependences take a uniform character.

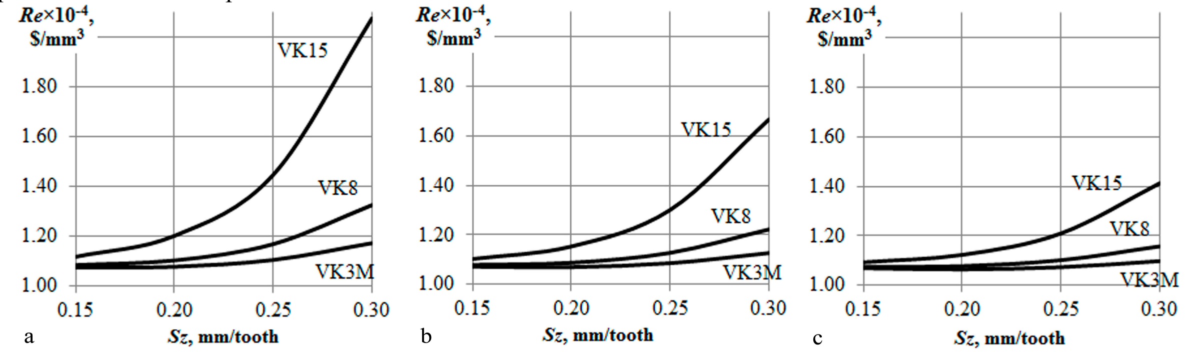

Fig. 1. Dependence of the resulted expenses of feed per tooth at the cutting depth t = 1.0 mm for the production of types: a - single; b - series; c – mass

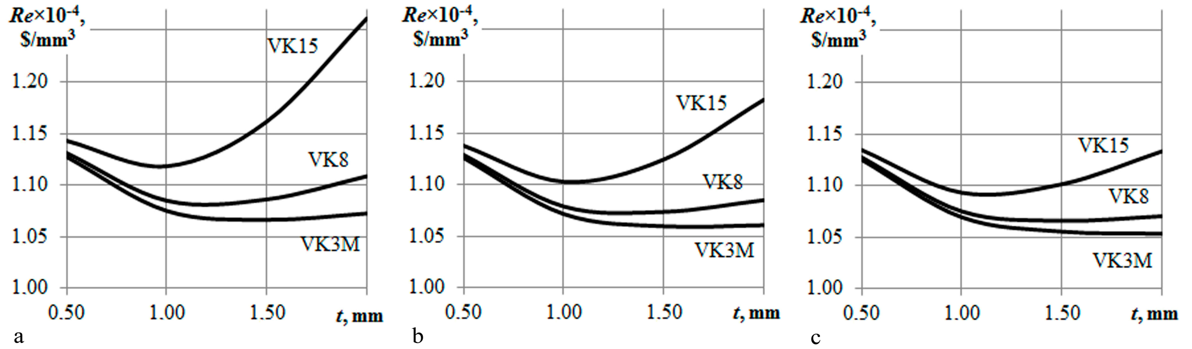

Fig. 2. Dependence of resulted expenses by cutting depth for feed per tooth S_z = 0.15 mm/tooth for production types: a - single; b - series; c - mass

At the same time, the dependence of the resulted expenses of the cutting depth is the extreme nature (Fig. 2). When the serial production of the minimum point of the resulted expenses is shifted towards increasing the depth of cut. Furthermore, the position of the minimum point shifts depending on the used tool material. Thus, in the unit for the production of hard alloy VK3M resulted expenses will be minimal when the cutting depth of 1.5 mm, for alloy VK8 – 1.2 mm, for alloy VK15 – 1.0 mm.

The extreme nature of the dependencies associated with a change in the period resistance of the cutting tool and increases the frequency of its change at the intensification of the cutting. When serial and mass production types increase the feed per tooth and cutting depth enables continuous processing performance gains and reduction in resulted expenses, since less time to replace the cutter.

4. Conclusions

The following conclusions and recommendations can be made on the results of research:

1. A method for determining the resulted expenses, allowing to optimize the parameters of composite materials processing, and improve production efficiency.
2. The mathematical dependence of the period resistance of the cutting tool of the cutting conditions, to predict the nature of the composite materials processing.
3. In order to reduce costs it is recommended to use hard alloy with high strength and hardness, for example, hard alloy VK3M brand or VK8.

4. The recommendations for the appointment of cutting conditions, ensuring minimal production costs:

- For a single production $S_z = 0.15 – 0.16$ mm/tooth, $t = 1.0 – 1.2$ mm;
- For serial production $S_z = 0.17 – 0.20$ mm/tooth, $t = 1.2 – 1.5$ mm;
- For mass production $S_z = 0.20 – 0.25$ mm/tooth, $t = 1.4 – 2.0$ mm.

Acknowledgements

This study was financially supported by the Ministry of Education and Science of the Russian Federation in the framework of young scientists grant of the President, carrying out long-term research and development in priority areas of modernization of the Russian economy.

References

[1] F.L. Matthews, R.D. Rawlings, Composite materials: engineering and science, The Alden Press, Oxford, England, 1999.
[2] F.M. Gallant, H.A. Bruck, S.E. Prickett, M. Cesarec, Graded polymer composites using twin-screw extrusion: a combinatorial approach to developing new energetic materials, Composites Part A: Applied Science and Manufacturing. 6 (2006) 957–969.
[3] A.V. Gorokhovsky, J.I. Escalante-Garcia, G.Yu. Gashnikova, L.P. Nikulina, S.E. Artemenko, Composite materials based on wastes of flat glass processing, Waste Management. 7 (2005) 733–736.
[4] D.L. Deborah, Composite materials: science and applications, Functional materials for modern technologies, Great Britain, 2004.
[5] S.N. Grigoriev, A.N. Krasnovskii, K.V. Kvachev, Investigation of impregnation fibrous materials in pultrusion process of polymer composite materials, International Polymer Science and Technology. 7 (2014) 59–62.
[6] V. Dhand, G. Mittal, K.Y. Rhee, S.-J. Park, D. Hui, A short review on basalt fiber reinforced polymer composites, Composites Part B: Engineering. 73 (2015) 166–180.
[7] A.S. Yuanyushkin, D.A. Rychkov, D.V. Lobanov, Surface quality of the fiberglass composite material after milling, Applied mechanics and materials. 682 (2014) 183–187.
[8] A.S. Yanyushkin, D.V. Lobanov, D.A. Rychkov, Automation tool preparation in the conditions of production, Applied Mechanics and Materials. 770 (2015) 739–743.
[9] I.G.Matis, Methods and means of inspecting the quality of composite materials, Russian Journal of Nondestructive Testing. 4 (1991) 277–285.
[10] E. Lemma, L. Chen, E. Siores, J. Wang, Study of cutting fiber-reinforced composites by using abrasive water-jet with cutting head oscillation, Composite Structures. 1–4 (2002) 297–303.
[11] Y.A. Zaykin, U.P. Koztaeva, Radiation-induced processes and internal friction in polymer-based composite materials, Radiation Physics and Chemistry. 4 (2000) 387–395.
[12] V.N. Bakulin, A.A. Larin, V.I. Reznichenkod, Improving the quality of manufactureof polymer-composite products using computed tomography as a nondestructive-testing method, Journal of Engineering Physics and Thermophysics. 2 (2015) 556–560.
[13] D.V. Lobanov, A.S. Yanyushkin, D.A. Rychkov, N.P. Petrov, Optimal organization of tools for machining composites, Russian Engineering Research. 2 (2011) 156–157.
[14] V.Yu. Skeeba, V.V. Ivancivsky, V.N. Pushnin, Numerical modeling of steel surface hardening in the process of high energy heating by high frequency currents, Applied Mechanics and Materials. 698 (2015) 288–293.
[15] N.V. Plotnikova, A.A. Losinskaya, V.Yu. Skeeba, E. Nikitenko, Perspective of high energy heating implementation for steel surface saturation with carbon, Applied Mechanics and Materials. 698 (2015) 351–354.
[16] P.V. Arkhipov, A.S. Yanyushkin, D.V. Lobanov, S.I. Petrushin, The effect of diamond tool performance capability on the quality of processed surface, Applied mechanics and materials. 379 (2013) 124–130.
[17] A.S. Yanyushkin, N.A. Saprykina, O.I. Medvedeva, Mechanism of protective membrane formation on the surface of metal-bonded diamond disks, Applied Mechanics and Materials. 682 (2014) 327–331.
[18] A.S. Yanyushkin, D.V. Lobanov, P.V. Arkhipov, V.V. Ivancivsky, Contact processes in grinding, Applied Mechanics and Materials. 788 (2015) 17–21.
[19] J.L. Bailleul, V. Sobotka, D. Delaunay, Y. Jarny, Inverse algorithm for optimal processing of composite materials, Composites Part A: Applied Science and Manufacturing. 8 (2003) 695–708.
[20] V.N. Fomin, E.B. Malyukova, A.A. Berlin, Criteria for optimization of processing and fabrication of polymer composite materials, Doklady Chemistry. 4–6 (2004) 39–41.