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Modelling surface roughness in finish turning as a function of cutting tool geometry using the response surface method, Gaussian process regression and decision tree regression

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ABSTRACT

In this study, the modelling of arithmetical mean roughness after turning of C45 steel was performed. Four parameters of cutting tool geometry were varied, i.e.: corner radius *r*, approach angle *κ*, rake angle *γ* and inclination angle *λ*. After turning, the arithmetical mean roughness *Ra* was measured. The obtained values of *Ra* ranged from 0.13 μm to 4.39 μm. The results of the experiments showed that surface roughness improves with increasing corner radius, increasing approach angle, increasing rake angle, and decreasing inclination angle. Based on the experimental results, models were developed to predict the distribution of the arithmetical mean roughness using the response surface method (RSM), Gaussian process regression with two kernel functions, the sequential exponential function (GPR-SE) and Mattern (GPR-Mat), and decision tree regression (DTR). The maximum percentage errors of the developed models were 3.898 %, 1.192 %, 1.364 %, and 0.960 % for DTR, GPR-SE, GPR-Mat, and RSM, respectively. In the worst case, the maximum absolute errors were 0.106 μm, 0.017 μm, 0.019 μm, and 0.011 μm for DTR, GPR-SE, GPR-Mat, and RSM, respectively. The results and the obtained errors show that the developed models can be successfully used for surface roughness prediction.

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References

[1] Kramar, D., Cica, D. (2021). Modeling and optimization of finish diamond turning of spherical surfaces based on response surface methodology and cuckoo search algorithm, *Advances in Production Engineering & Management*, Vol. 16, No. 3, 326-334, doi: 10.14743/apem2021.3.403.

[2] Sterpin Valic, G., Cukor, G., Jurkovic, Z., Brezocnik, M. (2019). Multi-criteria optimization of turning of martensitic stainless steel for sustainability, *International Journal of Simulation Modelling*, Vol. 18, No. 4, 632-642, doi: 10.2507/IJSIMM18(4)495.

[3] Ratnam, M.M. (2017). 1.1 Factors affecting surface roughness in finish turning, In: Hashmi, M.S.J. (ed.), *Comprehensive materials finishing*, Elsevier, Oxford, United Kingdom, 1-25, doi: 10.1016/B978-0-12-803581-8.09147-5.

[4] Kang, W.T., Derani, M.N., Ratnam, M.M. (2020). Effect of vibration on surface roughness in finish turning: Simulation study, *International Journal of Simulation Modelling*, Vol. 19, No. 4, 595-606, doi: 10.2507/IJSIMM19-4-531.

[5] Zerti, O., Yallese, M.A., Khettabi, R., Chaoui, K., Mabrouki, T. (2017). Design optimization for minimum technological parameters when dry turning of AISI D3 steel using Taguchi method, *International Journal of Advanced Manufacturing Technology*, Vol. 89, 1915-1934, doi: 10.1007/s00170-016-9162-7.

[6] Davoudinejad, A., Noordin, M.Y. (2014). Effect of cutting edge preparation on tool performance in hard-turning of DF-3 tool steel with ceramic tools, *Journal of Mechanical Science and Technology*, Vol. 28, 4727-4736, doi: 10.1007/s12206-014-1039-9.
[7] Zhao, T., Zhou, J.M., Bushlya, V., Ståhl, J.E. (2017). Effect of cutting edge radius on surface roughness and tool wear in hard turning of AISI 52100 steel, *International Journal of Advanced Manufacturing Technology*, Vol. 91, 3611-3618, doi: 10.1007/s00170-017-0065-z.
[8] Duc, P.M., Giang, L.H., Dai, M.D., Sy, D.T. (2020). An experimental study on the effect of tool geometry on tool wear and surface roughness in hard turning, *Advances in Mechanical Engineering*, Vol. 12, No. 9, 1-11, doi: 10.1177/1687814020959885.
[9] Neşeli, S., Yaldız, S., Türkeş, E. (2011). Optimization of tool geometry parameters for turning operations based on the response surface methodology, *Measurement*, Vol. 44, No. 3, 580-587, doi: 10.1016/j.measurement.2010.11.018.
[10] Ashish George, J., Lokesha, K. (2019). Optimisation and effect of tool rake and approach angle on surface roughness and cutting tool vibration, *SN Applied Sciences*, Vol. 1, Article No. 1133, doi: 10.1007/s42452-019-1175-z.
[11] Karim, Z., Azuan, S.A.S., Yasir, A. (2013). A study on tool wear and surface finish by applying positive and negative rake angle during machining, *Australian Journal of Basic and Applied Sciences*, Vol. 7, No. 10, 46-51.
[12] Kumar, S., Singh, D., Kalsi, N.S. (2019). Investigating the effect of approach angle and nose radius on surface quality of Inconel 718, *Journal of The Institution of Engineers (India): Series C*, Vol. 100, 121-128, doi: 10.1007/s40032-017-0411-9.
[13] Cui, X., Guo, J., Zheng, J. (2016). Optimization of geometry parameters for ceramic cutting tools in intermittent turning of hardened steel, *Materials & Design*, Vol. 92, 424-437, doi: 10.1016/j.matdes.2015.12.089.
[14] Sung, A.N., Loh, W.P., Ratnam, M.M. (2016). Simulation approach for surface roughness interval prediction in finish turning, *International Journal of Simulation Modelling*, Vol. 15, No. 1, 42-55, doi: 10.2507/IJSIMM15(1)4.320.
[15] Ponugoti, U., Dantuluri, R.R., Koka, N.S.S., Bhuvanagiri, R.S. (2020). Experimental investigations on the influence of cutting and tool geometry parameters over the machinability of AISI 52100 steel in hard turning, *International Journal of Modern Manufacturing Technologies*, Vol. 12, No. 1, 144-156.
[16] Senthilkumar, N., Tamizharasan, T. (2014). Effect of tool geometry in turning AISI 1045 steel: experimental investigation and FEM analysis, *Arabian Journal for Science and Engineering*, Vol. 39, 4963-4975, doi: 10.1007/s13369-014-1054-2.
[17] Tauhiduzzaman, M., Veldhuis, S.C. (2014). Effect of material microstructure and tool geometry on surface generation in single point diamond turning, *Precision Engineering*, Vol. 38, No. 3, 481-491, doi: 10.1016/j.precisioneng.2014.01.002.
[18] Abainia, S., Ouelaa, N. (2015). Experimental study of the combined influence of the tool geometry parameters on the cutting forces and tool vibrations, *International Journal of Advanced Manufacturing Technology*, Vol. 79, 1127-1138, doi: 10.1007/s00170-015-6885-9.
[19] Mohammad, R., Ariffin, M.K.A.M., Baharuddin, B.T.H.T., Mustapha, F., Aoyama, H. (2017). The effects of single cutting tool geometry on surface roughness, *Journal of Mechanical Engineering*, Vol. 3, No. 1, 45-54.
[20] Hai, S., Jung, H.-C., Shim, W.-H., Shin, H.-G. (2021). Investigation of surface quality for minor scale diameter of biodegradable magnesium alloys during the turning process using a different tool nose radius, *Metals*, Vol. 11, No. 8, Article No. 1174, doi: 10.3390/met11081174.
[21] Khellaf, A., Aouici, H., Smaiah, S., Boutabba, S., Yallese, M.A., Elbah, M. (2017). Comparative assessment of two ceramic cutting tools on surface roughness in hard turning of AISI H11 steel: Including 2D and 3D surface topography, *International Journal of Advanced Manufacturing Technology*, Vol. 89, 333-354, doi: 10.1007/s00170-016-9077-3.
[22] Özdemir, M. (2020). Modelling and prediction of effect of machining parameters on surface roughness in turning operations, *Tehnički Vjesnik – Technical Gazette,* Vol. 27, No. 3, 751-760, doi: 10.17559/TV-20190320104114.
[23] Kuntoğlu, M., Aslan, A., Pimenov, D.Y., Giasin, K., Mikolajczyk, T., Sharma, S. (2020). Modeling of cutting parameters and tool geometry for multi-criteria optimization of surface roughness and vibration via response surface methodology in turning of AISI 5140 steel, *Materials*, Vol. 13, No. 19, Article No. 4242, doi: 10.3390/ma13194242.
[24] Šarić, T., Vukelić, D., Šimunović, K., Svalina, I., Tadić, B., Prica, M., Šimunović, G. (2020). Modelling and prediction of surface roughness in CNC turning process using neural networks, *Tehnički Vjesnik – Technical Gazette,* Vol. 27, No. 6, 1923-1930, doi: 10.17559/TV-20200818114207.
[25] Zhang, P., Liu, Z. (2016). Modeling and prediction for 3D surface topography in finish turning with conventional and wiper inserts, *Measurement*, Vol. 94, 37-45, doi: 10.1016/j.measurement.2016.07.080.
[26] Benardos, P.G., Vosniakos, G.-C. (2003). Predicting surface roughness in machining: A review, *International Journal of Machine Tools and Manufacture*, Vol. 43, No. 8, 833-844, doi: 10.1016/S0890-6955(03)00059-2.
[27] Sousa, V.F.C., Silva, F.J.G. (2020). Recent advances in turning processes using coated tools –A comprehensive review, *Metals*, Vol. 10, No. 2, Article No. 170, doi: 10.3390/met10020170.
[28] Dureja, J.S., Gupta, V.K., Sharma, V.S., Dogra, M., Bhatti, M.S. (2016). A review of empirical modeling techniques to optimize machining parameters for hard turning applications, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, Vol. 230, No. 3, 389-404, doi: 10.1177/0954405414558731.
[29] He, C.L., Zong, W.J., Zhang, J.J. (2018). Influencing factors and theoretical modeling methods of surface roughness in turning process: State-of-the-art, *International Journal of Machine Tools and Manufacture*, Vol. 129, 15-26, doi: 10.1016/j.ijmachtools.2018.02.001.
[30] Puh, F., Jurkovic, Z., Perinic, M., Brezocnik, M., Buljan, S. (2016). Optimization of machining parameters for turning operation with multiple quality characteristics using Grey relational analysis, *Tehnički Vjesnik – Technical Gazette,* Vol. 23, No. 2, 377-382, doi: 10.17559/TV-20150526131717.

[31] Trung, D.D., Thinh, H.X. (2021). A multi-criteria decision-making in turning process using the MAIRCA, EAMR, MARCOS and TOPSIS methods: A comparative study, *Advances in Production Engineering & Management*, Vol. 16, No. 4, 443-456, doi: 10.14743/apem2021.4.412.

[32] Savićević, S., Vukćević, M., Klimenko, S.A., Tanović, L. (2017). Impact of cutting elements on forces and roughness of surface during turning hard steel X160 CrMo V12 with CBN tool, *Tehnički Vjesnik – Technical Gazette,* Vol. 24, No. 4, 1001-1006, doi: 10.17559/TV-20161013100743.

[33] Ortuño, F.M., Valenzuela, O., Prieto, B., Saez-Lara, M.J., Torres, C., Pomares, H., Rojas, I. (2015). Comparing different machine learning and mathematical regression models to evaluate multiple sequence alignments, *Neurocomputing*, Vol. 164, 123-136, doi: 10.1016/j.neucom.2015.01.080.

[34] Breiman, L., Friedman, J., Olshen, R.A., Stone, C.J (1984). *Classification and regression trees*, First edition, CRC Press, Boca Raton, Florida, USA, doi: 10.1201/9781315139470.

[35] Rasmussen, C.E., Williams, C.K.I. (2006). *Gaussian processes for machine learning*, MIT Press, Cambridge, United Kingdom, doi: 10.7551/mitpress/3206.001.0001.

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Izvirni znanstveni članek

Modeliranje površinske hrapavosti pri finem struženju kot funkcije geometrije rezalnega orodja z uporabo metode odzivne površine, regresije z Gaussovim procesom in regresije z odločitvenim drevesom

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P O V Z E T E K

V tej študiji je bilo izvedeno modeliranje aritmetične srednje hrapavosti po struženju jekla C45. Spreminjali smo štiri parametre geometrije rezalnega orodja, to so: radij konice *r*, pristopni kot *κ*, nagibni kot *γ* in naklonski kot *λ*. Po struženju je bila izmerjena aritmetična srednja hrapavost *Ra*. Vrednosti *Ra* so znašale od 0,13 µm do 4,39 µm. Rezultati poskusov so pokazali, da se površinska hrapavost izboljšuje s povečevanjem radija konice, povečanjem pristopnega kota, povečanjem nagibnega kota in zmanjšanjem naklonskega kota. Na podlagi rezultatov poskusa so bili razviti modeli za napoved porazdelitve aritmetične srednje hrapavosti z metodo odzivne površine (RSM), regresije z Gaussovim procesom z dvema jedrnima funkcijama; zaporedno eksponentno funkcijo (GPR-SE) ter Mattern (GPR-Mat) in regresijo z odločitvenim drevesom (DTR). Največje relativne napake razvitih modelov so bile 3,898 %, 1,192 %, 1,364 % in 0,960 % za DTR, GPR-SE, GPR-Mat in RSM. V najslabšem primeru so bile največje absolutne napake 0,106 µm, 0,017 µm, 0,019 µm in 0,011 µm za DTR, GPR-SE, GPR-Mat in RSM. Rezultati in ugotovljene napake kažejo, da se razviti modeli lahko uspešno uporabljajo za napoved hrapavosti površin.

P O D A T K I O Č L A N K U

Ključne besede:
Struženje;
Geometrija orodja;
Modeliranje;
Hrapavost površine;
Metoda odzivne površine;
Regresija z odločitvenim drevesom;
Regresija z Gaussovim procesom

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