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Optimizing rock breaking performance: The influence of chamfer on polycrystalline diamond compact (PDC) cutters

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ABSTRACT

Research on the rock-breaking performance of the Polycrystalline Diamond Compact (PDC) cutter has primarily focused on sharp cutters, often overlooking the influence of chamfer. Notably, the design of chamfer parameters has been largely unreported. In this study, we established a theoretical model of cutting force that takes chamfer into account. We analysed the primary and secondary relationships of four factors – back rake angle, depth of cut, chamfer angle, and chamfer length – on the force of the PDC cutter. This was done through a pseudo-level orthogonal level test. A numerical simulation, based on the Smooth Particle Hydrodynamic (SPH) method, was conducted to analyse the rock-breaking force and stress distribution characteristics of PDC cutters with different chamfer angles. Combined with a drop hammer impact test, we provided an optimized design of chamfer parameters. Our findings revealed that while the chamfer had a relatively minor influence on the force of the PDC cutter, it contributed to the optimal distribution of stress on the PDC cutter. This effectively protected the cutting edge and prevented early cracks and spalls of the cutter. When the chamfer angle was less than or equal to the back rake angle, the resultant force of the PDC cutter increased with the increase of the chamfer angle. However, when the chamfer angle was greater than the back rake angle, the resultant force of the PDC cutter first increased and then slightly decreased with the increase of the chamfer angle. Additionally, the resultant force of the PDC cutter increased approximately linearly with the increase of chamfer length. When the chamfer angle of the PDC cutter was between 30° and 45°, the fluctuation of the cutting force was relatively smooth, the rock-breaking process was stable, and the cutter's impact resistance energy was relatively higher. These findings will provide valuable guidelines for the design of chamfered PDC cutters.

ARTICLE INFO

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References

[1] Rajabov, V., Miska, S., Mortimer, L., Yu, M., Ozbayoglu, E. (2012). The effects of back rake and side rake angles on mechanical specific energy of single PDC cutters with selected rocks at varying depth of cuts and confining pressures, In: *Proceedings of the IADC/SPE Drilling Conference and Exhibition*, San Diego, California, USA, 1-17, doi: 10.2118/151406-MS.

[2] Zhang, Z., Zhao, D., Zhao, Y., Gao, K., Zhang, C., Lü, X. (2023). 3D numerical simulation study of rock breaking of the wavy PDC cutter and field verification, *Journal of Petroleum Science and Engineering*, Vol. 203, Article No. 108578, doi: 10.1016/j.petrol.2021.108578.

[3] Adzis, A.H.A., Abdul-Rani, A.M., Yi, K.Y., Maulianda, B.T., Rao, T.V.V.L.N. (2018). Effect of back rake angle and shape on wear rate of PDC cutter in hard formation, In: *Proceedings of the 6th International Conference on Production, Energy and Reliability*, *World Engineering Science & Technology Congress (ESTCON),* Kuala Lumpur, Malaysia, 1-9, doi: 10.1063/1.5075585.

[4] Dai, X.-W., Huang, Z.-W., Huang, P.-J., Chen, P.-J., Shi, H.-Z., Yan, S. (2023). Experimental investigation on the cuttings formation process and its relationship with cutting force in single PDC cutter tests, *Petroleum Science*, Vol. 20, No. 3, 1779-1787, doi: 10.1016/j.petsci.2022.10.021.

[5] Li, Y., Chen, Z., Ye, Y., Yang, Y. (2021). Combined finite-discrete element method for modeling the interaction between single PDC cutter and brittle rock, *Journal of Petroleum Science and Engineering*, Vol. 207, Article No. 109133, doi: 10.1016/j.petrol.2021.109133.
[6] Rahmani, R., Pastusek, P., Yun, G., Roberts, T. (2020). Investigation of geometry and loading effects on PDC cutter structural integrity in hard rocks, In: *Proceedings of the IADC/SPE International Drilling Conference and Exhibition*, Galveston, Texas, USA, 1-22, doi: 10.2118/199598-MS.
[7] Joodi, B., Sarmadivaleh, M., Rasouli, V., Nabipour, A. (2012). Simulation of the cutting action of a single PDC cutter using DEM, *Petroleum and Mineral Resources*, Vol. 81, 143-150, doi: 10.2495/PMR120131.
[8] Rostamsowlat, I., Akbari, B., Evans, B. (2018). Analysis of rock cutting process with a blunt PDC cutter under different wear flat inclination angles, *Journal of Petroleum Science and Engineering*, Vol. 171, 771-783, doi: 10.1016/j.petrol.2018.06.003.
[9] Zhang, C., Wang, J., Ke, X., Feng, X., Yang, Y., Ren, H., Huang, Z. (2023). Experimental study on working mechanics of PDC bit with worn teeth, *Diamond & Abrasives Engineering*, Vol. 43, No. 1, 35-42.
[10] Yang, Y., Xie, S., Cai, C., Cao, Y., Li, B. (2023). A study on the mechanism of heat generation law of PDC wear tooth cutting, *Journal of Southwest Petroleum University (Science & Technology Edition)*, Vol. 45, No. 1, 180-188, doi: 10.11885/j.issn.1674-5086.2020.06.04.03.
[11] Liu, W., Deng, H., Liu, Y., Chen, X., He, C., Zhu, X. (2023). Experimental investigation of the rock cutting process with blunt PDC cutters, *Geoenergy Science and Engineering*, Vol. 226, Article No. 211803, doi: 10.1016/j.geoen.2023.211803.
[12] Baker Hughes. StabilisX shaped-cutter technology, from *https://www.bakerhughes.com/drilling/drill-bits/shapedcutter-technology/stabilisx-shapedcutter-technology*, accessed July 28, 2023.
[13] Shao, F., Liu, W., Gao, D. (2021). Effects of the chamfer and materials on performance of PDC cutters, *Journal of Petroleum Science and Engineering*, Vol. 205, Article No. 108887, doi: 10.1016/j.petrol.2021.108887.
[14] Fu, Z., Tergeist, M., Kueck, A., Ostermeyer, G.-P. (2022). Investigation of the cutting force response to a PDC cutter in rock using the discrete element method, *Journal of Petroleum Science and Engineering*, Vol. 213, Article No. 110330, doi: 10.1016/j.petrol.2022.110330.
[15] Akbari, B., Miska, S. (2016). The effects of chamfer and back rake angle on PDC cutters friction, *Journal of Natural Gas Science and Engineering*, Vol. 35, Part A, 347-353, doi: 10.1016/j.jngse.2016.08.043.
[16] Jamaludin, A.A., Mehat, N.M., Kamaruddin, S. (2019). Optimizing wear rate for PDC cutter using Taguchi's technique and response surface methodology a comparative analysis, *International Journal of Engineering & Technology*, Vol. 8, No. 3, 155-161.
[17] Detournay, E., Defourny, P. (1992). A phenomenological model for the drilling action of drag bits, *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, Vol. 29, No. 1, 13-23, doi: 10.1016/0148-9062(92)91041-3.
[18] Zhang, Z., Zhou, Q., Zhang, K., Zheng, G., Zhang, T. (2019). Analysis of the influence of rock cutting depth on the temperature distribution of cutter, *Journal of China Coal Society*, Vol. 44, No. S2, 492-501, doi: 10.13225/j.cnki.jccs.2019.0949.
[19] Ju, P., Tian, D., Tian, H. (2023). Simulation and experimental study on rock disintegration characteristics of special-shaped PDC cutters, *Gazi University Journal of Science*, Vol. 36, No, 1, 414-428, doi: 10.35378/gujs.927956.
[20] Yahiaoui, M., Paris, J.-Y., Delbé, K., Denape, J., Gerbaud, L., Dourfaye, A. (2016). Independent analyses of cutting and friction forces applied on a single polycrystalline diamond compact cutter, *International Journal of Rock Mechanics & Mining Sciences*, Vol. 85, 20-26, doi: 10.1016/j.ijrmms.2016.03.002.
[21] Munoz, H., Taheri, A., Chanada, E. (2016). Rock cutting characteristics on soft-to-hard rocks under different cutter inclinations, *International Journal of Rock Mechanics and Mining Sciences*, Vol, 87, 85-89, doi: 10.1016/j.ijrmms.2016.05.014.
[22] Rostamsowlat, I., Richard, T., Evans, B. (2018). An experimental study of the effect of back rake angle in rock cutting, *International Journal of Rock Mechanics and Mining Sciences,* Vol. 107, 224-232, doi: 10.1016/j.ijrmms.2018.04.046.
[23] Zhu, X.H., Wang, Y.F., Liu, W.J., Tan, B., Luo, Y.X., Li, Z.L. (2023). A new method for evaluating the rock cutting and breaking performance of PDC cutters in heterogeneous granites, *Natural Gas Industry*, Vol. 43, No. 4, 137-147.
[24] Ju, P., Tian, D., Wang, C., Tian, H. (2021). Theoretical and simulation analysis on rock breaking mechanical properties of arc-shaped PDC bit, *Energy Reports*, Vol. 7, 6690-6699, doi: 10.1016/j.egyr.2021.09.148.
[25] Mazen, A.Z., Rahmanian, N., Mujtaba, I.M., Hassanpour, A. (2021). Effective mechanical specific energy: A new approach for evaluating PDC bit performance and cutters wear, *Journal of Petroleum Science and Engineering*, Vol. 196, Article No. 108030, doi: 10.1016/j.petrol.2020.108030.
[26] Xiong, C., Huang, Z.-W., Wang, L.-C., Shi, H.-Z., He, W.-H., Chen, Z.-L., Li, G.-S. (2023). Study on rock breaking characteristics and mechanism of conical PDC cutter, *Rock and Soil Mechanics*, Vol. 44, No. 8, 2432-2444.
[27] Kenneth, E., Russell, S.C. (2016). Innovative ability to change drilling responses of a PDC bit at the rigsite using interchangeable depth-of-cut control features, In: *Proceedings of the IADC/SPE Drilling Conference and Exhibition*, Fort Worth, Texas, USA, 1-10, doi: 10.2118/178808-MS.
[28] Wang, Y.L., Yang, L., Chen, J.H., Li, P. (2023). Supply chain game analysis based on mean-variance and price risk aversion under different power structures, *Advances in Production Engineering & Management*, Vol. 18, No. 1, 104-115, doi: 10.14743/apem2023.1.460.
[29] Ma, Y.C., Zhang, P., Huang, Z.Q., Deng, R., Yu, H.M. (2020). Optimal design for cutter-layout of global force balanced PDC bits, *China Mechanical Engineering*, Vol. 31, No, 20, 2412-2419, doi: 10.3969/j.issn.1004-132X.2020.20.003.

[30] Liu, S.B., Ni, H.J., Wang, Y., Zhang, H. (2021). Mechanism of multi-dimensional impact loads applied in increasing the rock cutting efficiency of a PDC bit, *Journal of Vibration and Shock*, Vol, 40, No, 2, 258-264, doi: 10.13465/j.cnki.jvs.2021.02.035.
[31] Fakhimi, A., Lanari, M. (2014). DEM-SPH simulation of rock blasting, *Computers and Geotechnics*, Vol. 55, 158-164, doi: 10.1016/j.compgeo.2013.08.008.
[32] Das, R., Cleary, P.W. (2010). Effect of rock shapes on brittle fracture using Smoothed Particle Hydrodynamics, *Theoretical and Applied Fracture Mechanics*, Vol. 53, No. 1, 47-60, doi: 10.1016/j.tafmec.2009.12.004.
[33] Bennett, K.C., Regueiro, R.A., Luscher, D.J. (2019). Anisotropic finite hyper-elastoplasticity of geomaterials with Drucker–Prager/Cap type constitutive model formulation, *International Journal of Plasticity*, Vol. 123, 224-250, doi: 10.1016/j.ijplas.2018.11.010.
[34] Huang, Z., Ma, Y., Li, Q., Xie, D. (2017). Geometry and force modelling, and mechanical properties study of polycrystalline diamond compact bit under wearing condition based on numerical analysis, *Advances in Mechanical Engineering*, Vol. 9, No. 6, 1-15, doi: 10.1177/1687814017702080.