APEM journal

**Advances in Production Engineering & Management**
Volume 17 | Number 2 | June 2022 | pp 193–204
https://doi.org/10.14743/apem2022.2.430

**ISSN 1854-6250**
Journal home: apem-journal.org
Original scientific paper

# Ultrasonic abrasive polishing of additive manufactured parts: An experimental study on the effects of process parameters on polishing performance

**Liu, X.**[a], **Wang, J.**[a,*], **Zhu, J.**[a], **Liew, P.J.**[b], **Li, C.**[c], **Huang, C.**[d]

[a]Marine Engineering College, Dalian Maritime University, Ganjingzi District, Dalian, P.R. China
[b]Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
[c]Xinyu Key Laboratory of Materials Technology and Application for Intelligent Manufacturing, Xinyu University, P.R. China
[d]College of Marine Engineering, Jimei University, Fujian, P.R. China

**ABSTRACT**

The rough surface of metal parts produced by the powder-based layered Additive Manufacturing (AM) technology such as Selective Laser Melting (SLM) is an important problem that needs to be solved. This study introduces obvious improvements in the surface quality of the AM parts by means of ultrasonic abrasive polishing (UAP), which uses cavitation collapse and micro-cut of abrasive particles for finishing surfaces. Experiments were conducted using the orthogonal experimental design method with an $L_9(3^4)$ orthogonal array to investigate the effects of ultrasonic power, machining time, abrasive particle size, and particle concentration on surface roughness *Ra* and material removal rate (MRR). The wear of the abrasive particles in the slurry was also studied. IN625 nickel-based alloy specimen manufactured by Selective Laser Melting (SLM) was chosen as the target workpiece. The results show that when the ultrasonic output power was too high, both surface quality and machining efficiency were deteriorated. And the surface roughness *Ra* was not further improved by just increasing the machining time. Severe cavitation erosion occurred in the polishing process and created leftover pits on the workpiece surface, which has a large influence on *Ra*. The size and amount of the abrasive particles should be within a certain range, which is helpful for material removal and improving the polishing performance. The work is useful for studying the influential process parameters involved in UAP and finding out the appropriate conditions.

**ARTICLE INFO**

*Keywords:*
Additive manufacturing;
3D printing;
Selective laser melting (SLM);
Ultrasonic abrasive polishing;
Process parameters;
Surface roughness;
Material removal rate;
Orthogonal array tests

**Corresponding author:*
wjs@dlmu.edu.cn
(Wang, J.)

*Article history:*
Received 19 January 2022
Revised 14 August 2022
Accepted 21 August 2022



## References

[1] ASTM International. (2015). ISO/ASTM52900-15 Standard terminology for additive manufacturing-general principles- terminology, West Conshohocken, PA: ASTM International.
[2] Mandić, M., Galeta, T., Raos, P., Jugović, V. (2016). Dimensional accuracy of camera casing models 3D printed on Mcor IRIS: A case study, *Advances in Production Engineering & Management,* Vol. 11, No. 4, 324-332, doi: 10.14743/apem2016.4.230.
[3] Mendricky, R., Soni, R.D. (2022). Geometric stability of parts produced by 3D printing, *Tehnički Vjesnik – Technical Gazette,* Vol. 29, No. 1, 23-29, doi: 10.17559/TV-20191101110214.
[4] Han, X., Zhu, H., Nie, X., Wang, G., Zeng, X. (2018). Investigation on selective laser melting AlSi10Mg cellular lattice strut: Molten pool morphology, surface roughness and dimensional accuracy, *Materials,* Vol. 11, No. 3, Article No. 392, doi: 10.3390/ma11030392.

[5] Calignano, F., Peverini, O.A., Addamo, G., Iuliano, L. (2020). Accuracy of complex internal channels produced by laser powder bed fusion process, *Journal of Manufacturing Processes,* Vol. 54, 48-53, doi: 10.1016/j.jmapro.2020.02.045.
[6] Calignano, F., Manfredi, D., Ambrosio, E.P., Biamino, S., Lombardi, M., Atzeni, E., Salmi, A., Minetola, P., Iuliano, L., Fino, P. (2017). Overview on additive manufacturing technologies, *Proceedings of the IEEE,* Vol. 105, No. 4, 593-612, doi: 10.1109/JPROC.2016.2625098.
[7] Polanec, B., Kramberger, J., Glodež, S. (2020). A review of production technologies and materials for manufacturing of cardiovascular stents, *Advances in Production Engineering & Management,* Vol. 15, No. 4, 390-402, doi: 10.14743/apem2020.4.373.
[8] Patalas-Maliszewska, J., Topczak, M. (2021). A new management approach based on Additive Manufacturing technologies and Industry 4.0 requirements, *Advances in Production Engineering & Management,* Vol. 16, No. 1, 125-135, doi: 10.14743/apem2021.1.389.
[9] Wei, C., Zhang, Z., Cheng, D., Sun, Z., Zhu, M., Li, L. (2021). An overview of laser-based multiple metallic material additive manufacturing: From macro-to micro-scales, *International Journal of Extreme Manufacturing*, Vol. 3, No. 1, Article No. 012003, doi: 10.1088/2631-7990/abce04.
[10] DebRoy, T., Wei, H.L., Zuback, J.S., Mukherjee, T., Elmer, J.W., Milewski, J.O., Beese, A.M., Wilson-Heid, A., De, A., Zhang, W. (2018). Additive manufacturing of metallic components – Process, structure and properties, *Progress in Materials Science,* Vol. 92, 112-224, doi: 10.1016/j.pmatsci.2017.10.001.
[11] Lewandowski, J.J., Seifi, M. (2016). Metal additive manufacturing: A review of mechanical properties, *Annual Review of Materials Research,* Vol. 46, 151-186, doi: 10.1146/annurev-matsci-070115-032024.
[12] Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C.B., Wang, C.C.L., Shin, Y.C., Zhang, S., Zavattieri, P.D. (2015). The status, challenges, and future of additive manufacturing in engineering, *Computer-Aided Design*, Vol. 69, 65-89, doi: 10.1016/j.cad.2015.04.001.
[13] ASTM International. (2013). *Standard Terminology for Additive Manufacturing Technologies,* ASTM International 2013 F2792–12a.
[14] Kozior, T. (2020). Rheological properties of polyamide PA 2200 in SLS technology, *Tehnički Vjesnik – Technical Gazette,* Vol. 27, No. 4, 1092-1100, doi: 10.17559/TV-20190225122204.
[15] Wang, J., Liu, S., Fang, Y., He, Z. (2020). A short review on selective laser melting of H13 steel, *International Journal of Advanced Manufacturing Technology,* Vol. 108, 2453-2466, doi: 10.1007/s00170-020-05584-4.
[16] Strano, G., Hao, L., Everson, R.M., Evans, K.E. (2013). Surface roughness analysis, modelling and prediction in selective laser melting, *Journal of Materials Processing Technology,* Vol. 213, No. 4, 589-597, doi: 10.1016/j.jmatprotec.2012.11.011.
[17] Bhaduri, D., Penchev, P., Batal, A., Dimov, S., Soo, S.L., Sten, S., Harrysson, U., Zhang, Z., Dong, H. (2017). Laser polishing of 3D printed mesoscale components, *Applied Surface Science,* Vol. 405, 29-46, doi: 10.1016/j.apsusc.2017.01.211.
[18] Cabanettes, F., Joubert, A., Chardon, G., Dumas, V., Rech, J., Grosjean, C., Dimkovski, Z. (2018). Topography of as built surfaces generated in metal additive manufacturing: A multi scale analysis from form to roughness, *Precision Engineering,* Vol. 52, 249-265, doi: 10.1016/j.precisioneng.2018.01.002.
[19] Gordon, E.R., Shokrani, A., Flynn, J.M., Goguelin, S., Barclay, J., Dhokia, V. (2016). A surface modification decision tree to influence design in additive manufacturing, In: Setchi, R., Howlett, R., Liu, Y., Theobald, P. (eds.), *Sustainable design and manufacturing 2016. SDM 2016. Smart innovation, systems and technologies, Vol. 52,* Springer, Cham, Switzerland, doi: 10.1007/978-3-319-32098-4_36.
[20] Kumbhar, N.N., Mulay, A.V. (2018). Post processing methods used to improve surface finish of products which are manufactured by additive manufacturing technologies: A review, *Journal of The Institution of Engineers (India): Series C, Mechanical, Production, Aerospace and Marine Engineering,* Vol. 99, 481-487, doi: 10.1007/s40032-016-0340-z.
[21] Tan, K.L., Yeo, S.H. (2020). Surface finishing on IN625 additively manufactured surfaces by combined ultrasonic cavitation and abrasion, *Additive Manufacturing,* Vol. 31, Article No. 100398, doi: 10.1016/j.addma.2019.100938.
[22] Nagalingam, A.P., Yuvaraj, H.K., Yeo, S.H. (2020). Synergistic effects in hydrodynamic cavitation abrasive finishing for internal surface-finish enhancement of additive-manufactured components, *Additive Manufacturing,* Vol. 33, Article No. 101110, doi: 10.1016/j.addma.2020.101110.
[23] Zhao, C., Qu, N., Tang, X. (2021). Removal of adhesive powders from additive-manufactured internal surface via electrochemical machining with flexible cathode, *Precision Engineering,* Vol. 67, 438-452, doi: 10.1016/j.precisioneng.2020.11.003.
[24] Lee, J.-Y., Nagalingam, A.P., Yeo, S.H. (2020). A review on the state-of-the-art of surface finishing processes and related ISO/ASTM standards for metal additive manufactured components, *Virtual and Physical Prototyping,* Vol. 16, No. 1, 68-96, doi: 10.1080/17452759.2020.1830346.
[25] Wang, J., Zhu, J., Liew, P.J. (2019). Material removal in ultrasonic abrasive polishing of additive manufactured components, *Applied Sciences,* Vol. 9, No. 24, Article No. 5359, doi: 10.3390/app9245359.
[26] Tan, K.L., Yeo, S.H. (2017). Surface modification of additive manufactured components by ultrasonic cavitation abrasive finishing, *Wear*, Vol. 378-379, 90-95, doi: 10.1016/j.wear.2017.02.030.
[27] Ichida, Y., Sato, R., Morimoto, Y., Kobayashi, K. (2005). Material removal mechanisms in non-contact ultrasonic abrasive machining, *Wear,* Vol. 258, No. 1-4, 107-114, doi: 10.1016/j.wear.2004.05.016.
[28] Whillock, G., Harvey, B.F. (1997). Ultrasonically enhanced corrosion of 304L stainless steel II: The effect of frequency, acoustic power and horn to specimen distance, *Ultrasonics Sonochemistry,* Vol. 4, No. 1, 33-38, doi: 10.1016/S1350-4177(96)00015-6.
[29] Virot, M., Chave, T., Nikitenko, S.I., Shchukin, D.G., Zemb, T., Möhwald, H. (2010). Acoustic cavitation at the water-glass interface, *Journal of Physical Chemistry C*, Vol. 114, No. 30, 13083-13091, doi: 10.1021/jp1046276.

[30] Couppis, E.C., Klinzing, G.E. (1974). Effect of cavitation on reacting systems, *AIChE Journal,* Vol. 20, No. 3, 485-491, doi: 10.1002/aic.690200308.
[31] Shchukin, D.G., Skorb, E., Belova, V., Möhwald, H. (2011). Ultrasonic cavitation at solid surfaces, *Advanced Materials,* Vol. 23, No. 17, 1922-1934, doi: 10.1002/adma.201004494.
[32] Bhosale, S.B., Pawade, R.S., Brahmankar, P.K. (2014). Effect of process parameters on MRR, TWR and surface topography in ultrasonic machining of alumina–zirconia ceramic composite, *Ceramics International,* Vol. 40, No. 8, Part B, 12831-12836, doi: 10.1016/j.ceramint.2014.04.137.
[33] Tzanakis, I., Eskin, D.G., Georgoulas, A., Fytanidis, D.K. (2014). Incubation pit analysis and calculation of the hydrodynamic impact pressure from the implosion of an acoustic cavitation bubble, *Ultrasonics Sonochemistry,* Vol. 21, No. 2, 866-878, doi: 10.1016/j.ultsonch.2013.10.003.