Reviews on Advanced Materials and Technologies, 2026, vol. 8, no. 3, pp. 135–142
DOI: 10.17586/2687-0568-2026-8-3-135-142

Estimation of Additive Manufactured Steel Hardness and Elastic Modulus by Instrumented Indentation Test

K.I. Doronin, A.S. Umanskii, A.V. Kondratev

Department of Metrology, Instrumentation and Quality Management, Empress Catherine II Saint Petersburg Mining University, 21st Line, 2, St Petersburg, 199106, Russia

Received: July 25, 2026 Corresponding author: K.I. Doronin

Abstract. This work is devoted to mechanical properties estimation of steel samples produced by additive and classic technologies via instrumented indentation test. Features of 3D printing, physical and mechanical properties, methods and means of additive manufacturing products control are described. The experimental part presents a series of indentation tests to determine the parameters of elastic-plastic deformation: hardness and elastic modulus, which are compared to reference data from other studies. The difference in the properties of the material produced by classical technologies and synthesized by direct metal laser sintering (DMLS) from a powder of identical chemical composition is discussed. The elastic modulus varied less for DMLS samples (208–213 GPa) than for cast ones (203–234 GPa). Hardness of the additively manufactured 12Cr18Ni10Ti was also more consistent relative to the differently remelted samples.

Citation: Rev. Adv. Mater. Technol., 2026, vol. 8, no. 3, pp. 135–142

View online: https://doi.org/10.17586/2687-0568-2026-8-3-135-142

View Table of Contents: https://reviewsamt.com/issues

REFERENCES

1. K.V. Gogolinskiy, V.A. Syasko. Prospects and challenges of the Fourth Industrial Revolution for instrument engineering and metrology in the field of non-destructive testing and condition monitoring. *Insight - Non-Destructive Testing and Condition Monitoring*, 2019, vol. 61, no. 8, pp. 434–440.
2. L. Ben Said, B. Ayadi, S. Alharbi, F. Dammak. Recent advances in additive manufacturing: A review of current developments and future directions. *Machines*, 2025, vol. 13, no. 9, art. no. 813.

3. W.E. Frazier. Metal additive manufacturing: A review. *Journal of Materials Engineering and Performance*, 2014, vol. 23, no. 6, pp. 1917–1928.
4. C.Y. Yap, C.K. Chua, Z.L. Dong, Z.H. Liu, D.Q. Zhang, L.E. Loh, S.L. Sing. Review of selective laser melting: Materials and applications. *Applied Physics Reviews*, 2015, vol. 2, no. 4, art. no. 041101.
5. J.J. Lewandowski, M. Seifi. Metal additive manufacturing: A review of mechanical properties. *Annual Review of Materials Research*, 2016, vol. 46, pp. 151–186.
6. L. Guo, L. Zhang, J. Andersson, O. Ojo. Additive manufacturing of 18% nickel maraging steels: Defect, structure and mechanical properties: A review. *Journal of Materials Science & Technology*, 2022, vol. 120, pp. 227–252.
7. A. Shrivastava, A.K. Subramaniyan, S. Rao, B.K. Nagesha. How to characterise the anisotropy of laser powder bed fusion-processed parts? Towards a surrogate, non-destructive indentation-based approach. *Journal of Manufacturing Processes*, 2024, vol. 118, pp. 128–153.
8. V.V. Maksarov, Nguyen Van Dao, A.D. Khalimonenko, P.V. Shishkin. Technological support of workpiece surface quality based on local cryogenic impact during processing of austenitic steels. *Chernye Metally*, 2024, no. 9, pp. 82–87. [In Russian]
9. A. Patel, B. Raphael. Robotic 3D printing of structural slabs using polyethylene waste as filler to reduce carbon footprint. *Construction Robotics*, 2024, vol. 8, art. no. 7.
10. D.G. Petrakov, G.M. Penkov, A.B. Zolotukhin. Experimental study on the effect of rock pressure on sandstone permeability. *Journal of Mining Institute*, 2022, vol. 254, pp. 244–251.
11. N.V. Pashkevich, V.S. Khloponina, N.A. Pozdnyakov, A.A. Avericheva. Analysing the problems of reproducing the mineral resource base of scarce strategic minerals. *Journal of Mining Institute*, 2024, vol. 270, pp. 1004–1023.
12. A.A. Vinogradova, K.V. Gogolinskiy, K.I. Doronin, E.K. Shchiptsova, A.V. Melnikova. HDPE properties evaluation via instrumented indentation: Experimental and computer simulation approach. *Applied Mechanics*, 2025, vol. 6, no. 2, art. no. 29.
13. L.-H. Kang. Non-destructive testing methods for products by additive manufacturing. *Journal of the Korean Society for Nondestructive Testing*, 2016, vol. 36, no. 4, pp. 308–314.
14. A. Hakami, S.A. Ojo, D.V. Abere, F.D. Uzuh, R.A. Robert. Advancements in metal additive manufacturing: Opportunities, limitations, impact on properties, and potential solutions: A review. *Progress in Additive Manufacturing*, 2025, vol. 10, pp. 4447–4495.
15. A.S. Zhukov, V.V. Madin, B.K. Barakhtin, S.N. Perevislov, P.A. Kuznetcov. Study of the structure and the destruction surface of the dampers manufactured by the selective laser melting. *Materials Science Forum*, 2023, vol. 1084, pp. 61–66.
16. Z. Snow, A.R. Nassar, E.W. Reutzel. Review of the formation and impact of flaws in powder bed fusion additive manufacturing. *Additive Manufacturing*, 2020, vol. 36, art. no. 101457.
17. N.P. Aleshin, M.V. Grigor'ev, N.A. Shchipakov, M.A. Prilutskii, V.V. Murashov. Using nondestructive testing methods for in-production quality control of additive manufactured parts. *Russian Journal of Nondestructive Testing*, 2016, vol. 52, no. 9, pp. 532–537.
18. A. Lopez, R. Bacelar, I. Pires, T.G. Santos, J.P. Sousa, L. Quintino. Non-destructive testing application of radiography and ultrasound for wire and arc additive manufacturing. *Additive Manufacturing*, 2018, vol. 21, pp. 298–306.
19. A.A. Popovich, D.V. Masaylo, V.Sh. Sufiiarov, E.V. Borisov, I.A. Polozov, V.A. Bychenok, I.Yu. Kinzhagulov, I.V. Berkutov, D.S. Ashikhin, A.V. Il'inskii. A laser ultrasonic technique for studying the properties of products manufactured by additive technologies. *Russian Journal of Nondestructive Testing*, 2016, vol. 52, no. 6, pp. 303–309.
20. N. Knezovic, B. Dolsak. In-process non-destructive ultrasonic testing application during wire plus arc additive manufacturing. *Advances in Production Engineering & Management*, 2018, vol. 13, no. 2, pp. 158–168.
21. S. Everton, P. Dickens, C. Tuck, B. Dutton. Using laser ultrasound to detect subsurface defects in metal laser powder bed fusion components. *JOM*, 2018, vol. 70, no. 3, pp. 378–383.
22. L.Y. Mogilner, V.A. Syasko, A.I. Shikhov. Modeling defects in ultrasonic nondestructive testing: State-of-the-art and prospects. *Russian Journal of Nondestructive Testing*, 2024, vol. 60, pp. 481–500.

23. Y. Altay, A.V. Fedorov, K.A. Stepanova, D.O. Kuzivanov. Experimental determination of the significance of statistical evaluation of parameters characterizing secondary diagnostic indicators of acoustic emission. *Journal of Instrument Engineering*, 2022, vol. 65, no. 10, pp. 735–746. [In Russian]
24. A.O. Rozanov, D.N. Petrov, A.M. Rozenbaum, A.A. Tereshkin, M.D. Ilinov. Acoustic emission precursor criteria of rock damage. In: *ISRM Regional Symposium - EUROCK 2018*, St. Petersburg, Russia, 22-26 May 2018, OnePetro, 2018, art. no. ISRM-EUROCK-2018-090.
25. M.A. Muktadir, M.N. Hasan, M. Alam. Additive manufacturing and acoustic emission: A brief review. *Journal of Additive Manufacturing Technologies*, 2023, vol. 2, no. 1, art. no. 632.
26. E. Loseva, I. Lozovsky, R. Zhostkov. Refining low strain pile integrity testing for minor flaw detection with complex wavelet transform. *Civil Engineering Journal*, 2024, vol. 10, no. 10, pp. 3194–3207.
27. G.G. Popov, V.I. Bolobov, A.O. Oparina, A.O. Shvets. Effect of hydrogenation on hardness of metallic materials used in oil and gas industry. *International Journal of Engineering*, 2025, vol. 38, no. 2, pp. 295–303.
28. P. Seensattayawong, C. Suwanpreecha, N. Boonlert, S. Songkuea, A. Manonukul. The effect of printing parameters on the properties of 17-4 PH stainless steel fabricated by material extrusion additive manufacturing. *Journal of Metals, Materials and Minerals*, 2024, vol. 34, no. 2, art. no. 1804.
29. N.P. Aleshin, V.V. Murashov, A.G. Evgenov, M.V. Grigoriev, N.A. Shchipakov, S.A. Vasilenko, I.S. Krasnov. The classification of flaws of metal materials synthesized by the selective laser melting method and the capabilities of nondestructive testing methods for their detection. *Russian Journal of Nondestructive Testing*, 2016, vol. 52, no. 1, pp. 38–43.
30. X. Jiang, W. Shen, L. Jiang, H. Qin. Effects of particle size distribution and impact speed on printing quality in direct energy deposition. *Manufacturing Letters*, 2022, vol. 33, pp. 521–526.
31. B. Karabulut, X. Ruan, S. MacDonald, J. Dobrić, B. Rossi. Fatigue of wire arc additively manufactured components made of unalloyed S355 steel. *International Journal of Fatigue*, 2024, vol. 184, art. no. 108317.
32. K. Solberg, E.W. Hovig, K. Sørby, F. Berto. Directional fatigue behaviour of maraging steel grade 300 produced by laser powder bed fusion. *International Journal of Fatigue*, 2021, vol. 149, art. no. 106229.
33. L. Li, Z. Li, M. Cao, Y. Tang, Z. Zhang. Nanoindentation and porosity fractal dimension of calcium carbonate whisker reinforced cement paste after elevated temperatures (up to 900°C). *Fractals*, 2021, vol. 29, no. 2, art. no. 2140001.
34. S.S. Kasyap, K. Senetakis. Application of nanoindentation in the characterization of a porous material with a clastic texture. *Materials*, 2021, vol. 14, no. 16, art. no. 4579.
35. E.L. Papazoglou, N.E. Karkalos, P. Karmiris-Obratański, A.P. Markopoulos. On the modeling and simulation of SLM and SLS for metal and polymer powders: A review. *Archives of Computational Methods in Engineering*, 2022, vol. 29, no. 2, pp. 941–973.
36. E.I. Pryakhin, D.A. Pribytkova. The influence of the quality of surface preparation of pipes for heating networks on their corrosion resistance during operation in underground conditions. *Chernye Metally*, 2023, vol. 11, pp. 97–102. [In Russian]
37. E. Yujra Rivas, A. Vyacheslavov, K.V. Gogolinskiy, K. Sapozhnikova, R. Taymanov. Deformation monitoring systems for hydroturbine head-cover fastening bolts in hydroelectric power plants. *Sensors*, 2025, vol. 25, no. 8, art. no. 2548.
38. S.B. Ermakov, B.S. Ermakov, S.A. Vologzhanina, O.I. Sleptsov. Investigation of material properties for cryogenic products, produced by additive manufacturing techniques. *Metallurgist*, 2023, vol. 67, pp. 644–651.
39. P.A. Kuznetsov, I.V. Shakirov, V.V. Bobyr', A.S. Zhukov, V.N. Klimov. Features of melt gas atomization and selective laser melting of high-strength austenitic nitrogen-containing steel powders. *Metal Science and Heat Treatment*, 2020, vol. 62, no. 1–2, pp. 76–80.
40. International Organisation for Standartization. *Metallic materials — Instrumented indentation test for hardness and materials parameters — Part 1: Test method*. ISO 14577-1:2015. ISO, Geneva, 2015.

41. W.C. Oliver, G.M. Pharr. An improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments. *Journal of Materials Research*, 1992, vol. 7, no. 6, pp. 1564–1583.
42. N.E. Gorji, R. O'Connor, D. Brabazon. XPS, SEM, AFM, and nano-indentation characterization for powder recycling within additive manufacturing process. *IOP Conference Series: Materials Science and Engineering*, 2021, vol. 1182, no. 1, art. no. 012025.
43. H. Peng, W. Fang, C. Dong, Y. Yi, X. Wei, B. Luo, S. Huang. Nano-mechanical properties and creep behavior of Ti6Al4V fabricated by powder bed fusion electron beam additive manufacturing. *Materials*, 2021, vol. 14, no. 11, art. no. 3004.
44. M.J. Uddin, E. Ramirez-Cedillo, R.A. Mirshams, H.R. Siller. Nanoindentation and electron backscatter diffraction mapping in laser powder bed fusion of stainless steel 316L. *Materials Characterization*, 2021, vol. 174, art. no. 111047.
45. A. Useinov, V. Reshetov, I. Maslenikov, A. Rusakov, E. Gladkih, V. Bespalov, B. Loginov. Study of properties of thin films in dynamic mechanical analysis mode using NanoScan-4D scanning nano-hardness tester. *Nanoindustry Russia*, 2016, no. 1, pp. 80–87.
46. W.C. Oliver, G.M. Pharr. Measurement of hardness and elastic modulus by instrumented indentation: Advances in understanding and refinements to methodology. *Journal of Materials Research*, 2004, vol. 19, pp. 3–20.
47. V.I. Moshchenok, I.V. Doshchechkina, I.E. Kukhareva, T.S. Skoblo, A.I. Sidashenko, M.V. Marchenko, V.M. Vlasovets. The influence of various factors on the errors in measuring the microhardness of the austenitic structural component of steel 12Cr18N10T. *Bulletin of the Kharkov National Automobile and Road University*, 2009, vol. 46, pp. 49–51. [In Russian]
48. H. Wang, A. Dhiman, H.E. Ostergaard, Y. Zhang, T. Siegmund, J.J. Kruzic, V. Tomar. Nanoindentation based properties of Inconel 718 at elevated temperatures: A comparison of conventional versus additively manufactured samples. *International Journal of Plasticity*, 2019, vol. 120, pp. 380–394.
49. M. Munther, T. Palma, F. Tavangarian, A. Beheshti, K. Davami. Nanomechanical properties of additively and traditionally manufactured nickel-chromium-based superalloys through instrumented nanoindentation. *Manufacturing Letters*, 2020, vol. 23, pp. 39–43.