PROFESSIONAL PAPER
DOI: 10.63395/STEDConf14022025959N303
Submitted: 16.09.2025.
Accepted: 30.10.2025.

ARTIFICAL INTELLIGENCE SUPPORTED APPLICATION FOR EXPLOSIVE CLADDING PROCESS SPECIFICATION

Zoltán Nyikes[1], Tünde Anna Kovács[2]

[1]Milton Friedman University, Kelta u. 2, 1039 Budapest, Hungary, nyikes.zoltan@uni-milton.hu
[2]Obuda University, Banki Donat Faculty of Mechanical and Safety Engineering, Bécsi út 96/B, H-1034 Budapest, Hungary, kovacs.tunde@bgk.uni-obuda.hu

Coresponding author: Zoltán Nyikes, Milton Friedman University, Kelta u. 2, 1039 Budapest, Hungary, nyikes.zoltan@uni-milton.hu

ABSTRACT

Explosive cladding is becoming increasingly widespread in the field of metalworking technologies. The advantage of this technology is that it cannot be combined with other welding technologies, and dissimilar metals can be joined by cohesion joint. The wide range of materials and the different properties of metallic materials (modulus of elasticity, tensile strength, hardness, ductility, etc.) are the reasons for the difficulty of determining the welding process specification. In addition, many explosives (with blast velocities below the speed of sound) are suitable for creating the appropriate bond strength. AI is a good tool for several applications and process parameter calculations. The innovative application supported by AI can help the welding engineer in the explosive welding process parameter determinations. For the welding process, the engineer chooses suitable metal and explosive materials. AI, based on the explosive material parameters and the metallic materials' mechanical properties, calculate the explosive welding setup parameters. In this article, the algorithm of the application and the theoretical and practical elements of the technological design are presented in detail. The developed application facilitates the technological design of the otherwise complex blast welding process.

Keywords: welding, AI, application, explosive cladding, algorithm.

INTRODUCTION

Welding is a widely used industrial application worldwide. Welding is a joining technology that establishes a cohesive bond. In the industrial area, it uses fusion and solid-state welding processes. The welding specification always depends on the materials and structures. For fusion welding processes, high-temperature heat is required because bonding is created by melting the materials. Fusion welding is practical for metals and specific polymers. Because of the wide variety of materials, fusion welding can't be applied in all cases. Solid-state welding is another group of welding processes, where bonding between materials is created without melting or partial melting of the components.

Solid-state welding processes, e.g., resistance spot welding, ultrasonic welding, and explosive welding. The process specification in the case of the solid-state welding processes is also a complex process. It needs to take into account the process, and firstly, the chemical, physical, and mechanical properties of the weldable materials. The second aspect in the case of the process selection is the product structure (thickness of the walls, design of the structure, etc.). Solid-state welding process means that the components are connected by force and sometimes with heat, but without melting. The bonding between atoms is achieved by bringing the atoms of the two components within the bonding distance with force.

Explosive welding is a specialised welding process among solid-state welding processes (Pocalyko, 1964; Holtzman, Cowan, 1965; Pocalyko, 1981). In this process it needs to take account the possibilities and the limits of the process and the welded materials. In the literature, one can find examples only for metallic materials. The most common process for bonding metal sheets ot plates (Findik, 2011; ASM Handbook 1992; Mousavi, Al-Hassani, 2005; Marc, et. al. 1980). It is possible to create butt welding by the explosive welding process, but in industrial applications, this is not feasible. The explosive welding process is useful for bonding large sheets and plates. For the explosive welding process, the energy to bond the materials came from the established gas pressure of the explosion (Zhang, Zhang, Feng, 2012; Liu, Zhang, Yang, 2011; Peters, 2005; Zhang, et. al., 2011). The wide range and different properties of explosives complicate the process specification. The process specification needs several calculations based on the weldable materials, structural properties, and explosive materials properties. To earn suitable parameters, it requires knowledge of the material properties and the calculation of the explosion welding process setup parameters (Havlícek, Havlícek, 2012; Meyers, Murr, 1980; Davis, 2002; Staudhammer, et. al., 1981; Zhang, 2008; Kovács-Coskun, 2016). It can be seen that the explosive welding process appears simple, but it requires calculation based on a large amount of data (Kugyela, et. al. 2025; Lukács, et. al. 2012; Hirsch, 1995; Catovic, 2020). The AI can be a valuable aid in achieving suitable results.

In recent years, significant changes have occurred in the approach to complex engineering problems (Kamaruzaman, et. al., 2017). The increasing volume of data (Quick, et. al., 2014), the number of variables to be managed (Sadeghi-Bazargani, et. al., 2011), and the need for precise adjustment have all contributed to a shift in how design processes (Grønbæk, et. al., 2017) are carried out. Calculations have become more demanding, and greater emphasis is now placed on finding effective methods to handle (Greenhalgh, et. al., 2005) them reliably and efficiently. Machine learning (Zhou, 2021) and intelligent software (Perkusich, 2020) are not there to think for us, but to take the monotonous, time-consuming work (Rios, 2020) off our shoulders and help us find the best solutions (Standley, 2010). This study presents three areas where artificial intelligence (AI) can help engineers (Patange, et. al., 2023): computing, database management, and application development (Wasserman, 2010) in the preparation of the explosive welding process (Greenberg, 2019). As every engineer knows, one of the most difficult parts of design is balancing all the different considerations: strong enough but not too expensive, lightweight but durable. In the past, this required many iterations, many experiments, and a lot of time. AI is a great help here because it can quickly run through thousands of variants and analyze them to find the best solutions. It is also useful for simulations (Jeon, et. al., 2016), such as choosing explosives or studying gap sizes, because it shortens calculation time while still providing accurate results. Another challenge in engineering is reviewing and managing huge amounts of data. Every project generates a lot of measurements, experience, and documentation (Alwazae, et. al., 2014). This is where AI comes in handy: it can connect data, recognize patterns, and even predict problems. For example, in explosive welding processes, AI uses machine data to indicate when the choice of explosive material is inappropriate or to recommend changes to the size of the gap. This not only saves time and money, but also improves quality. Nowadays, almost everyone has a smartphone, and engineers are no exception. More and more applications are being developed to facilitate engineering work (Ejiwale, 2014). Many of them already have built-in artificial intelligence: for example, they provide real-time bug fixes, optimization suggestions, or help solve more complex problems. The advantage of AI-compatible applications is that they are not only affordable for large companies, but also accessible to smaller offices and individual designers (Javaid, et. al., 2022). AI does not replace engineers, but helps them make better decisions and work faster. It makes it easier to navigate data and provides advanced tools that were previously unimaginableWhen used effectively, AI does not detract from the profession but enhances it: it makes design more accurate, efficient, and enjoyable.

AI is a valuable tool for data analysis, which supports the calculation of welding process parameters; however, it requires a welding expert to determine the final parameters.

MATERIAL AND METHODS OF WORK

In this research, we aimed to develop an AI-supported application that assists in specifying the explosive welding process. We focused on the use of metallic sheet or plate materials for explosive welding. This process is specifically referred to as cladding. Explosive cladding is a solid-state process in which controlled explosive detonations force two or more metals together at high pressures, resulting in a high-quality metallurgical bond between the colliding surfaces

Nyikes, Z., & Kovács, T.A. (2025). Artificial Intelligence supported application for explosive cladding process specification. *STED Conference 14*(2), 303-310.

(Holtzman, 1965; Pocalyko, 1981; Findik, 2011; ASM Handbook 1992; Mousavi, Al-Hassani, 2005).

Explosive Cladding

Figure 1 below shows the parallel setup of the explosion welding process, and Figure 2 shows the cross section of the explosive welded joint. The wave of the explosion pressure causes a special joint formation, which can be seen in the cross-section of the joint.

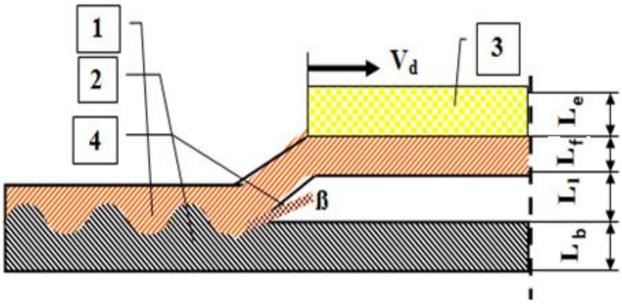

Figure 1. Setup of the explosion welding (1-clad plate, 2-base plate, 3-high explosive, 4-jet).

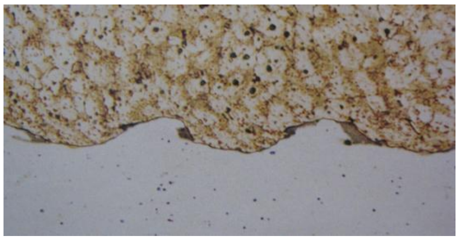

Figure 2. Cross-section of the explosive welded bond.

It is used for determining the setup parameters and the properties of the explosive material, as well as the properties of weldable metals, including material parameters and geometrical parameters (Kugyela, et. al., 2025). The calculation is suitable only for the parallel welding setup.

Based on the welding setup (Figure 1), it can be observed that the key process parameters are the gap size L_l and the thickness of the explosive material L_e. During the selection of explosive materials, it is necessary to consider a critical limit related to the detonation velocity of the explosive material. The sound velocity in the material needs to be smaller than the speed of the flyer sheet's collision v_c with the base plate (Kugyela, et. al., 2025; Lukács, et. al. 2012). Based on the literature data, the gap size L_l of the welding setup needs to be between the following range (Pocalyko, 1964; Hirsch, 2012; Catovic, 2020), where L_f is the thickness of the flyer plate:

$$0,5 \cdot L_f < L_l < 1,6 \cdot L_f \quad (1)$$

To determine the gap size of the welding setup, the following equation (2) can be found in the literature (Kugyela, et. al., 2025):

$$L_e = (\rho_f \cdot L_f)/\rho_e \quad (2)$$

where:

L_e – thickness of the explosive material (cm)
ρ_f – density of the flyer plate (g/cm^3)
L_f – thickness of the flyer plate (cm)
ρ_e – density of the explosive material (g/cm^3)

The key setup parameters are determined by the introduced method. Data on the selected explosive material and the flyer plate material properties are available from an internet database with AI assistance.

Artificial intelligence in flowchart design

A well-thought-out flowchart has always been a cornerstone of technology design (Whitfield, et. al., 2011). In industry and engineering practice, flowcharts have been used for decades to capture the steps of a system or production line in a clear and logical way. Such a diagram is not just a drawing, but a tool that facilitates communication between team members (Hedman, 2015), helps to identify errors and provides a basis for detailed calculations.

In recent years, engineers have come up with new tools that incorporate artificial intelligence (Pival, 2023). These systems can make predictions, suggest parameters, and often automatically produce sketches. While these tools are undoubtedly useful, it is important to understand that they can only be used effectively and safely with proper expert supervision and continuous monitoring.

Calculations and parameter setting

One of the most time-consuming parts of process design is parameter setting (Rios, et. al., 2020). When designing industrial processes, such as welding processes, a balance (Weman, 2011) must be found between dozens of input and output requirements: material thickness, material quality, explosive material, gap size, and costs. Calculating these manually, especially when there are many variables, requires significant resources.

Artificial intelligence can be of considerable help at this stage. The software can run hundreds or even thousands of combinations at once and recommend the parameter sets that best suit the specified objectives. In explosive welding, an AI-based tool (Goka, et. al., 2024) can predict the appropriate explosive material for different material qualities and thicknesses, its quantity, and the gap parameters, and then rank the options.

However, these results can only serve as a starting point. The engineer must make the final decision on which solution can be implemented based on practical experience and on-site conditions.

Flowchart generation

Automatic flowchart creation is a new feature of modern design software. The engineer enters the basic objectives into the system, such as the data of the materials to be welded and the explosive to be used, and the system creates a preliminary flowchart in logical order based on this information. This diagram includes the relationships between each step and the main elements. This approach proves especially helpful during the initial phase of planning, as it can reduce preparation time and make it easier to examine several alternatives. Even so, each proposal must be reviewed by someone with practical experience, since certain configurations may not meet regulatory requirements or may lead to unnecessary costs.

The role of peer review

Peer review is a key element in the design process. Artificial intelligence does not replace engineering experience and knowledge, but complements it. AI works only on the basis of inputs and algorithms and does not see the full context or perceive practical problems.

Therefore, all AI-generated flowcharts (Arbaz, et. al., 2024), calculations and proposals need to be manually reviewed, checked for reality and appropriateness of the results. In many places, it is good practice for plans to be reviewed jointly by several experts, who also provide feedback on each step to the system so that it can produce more accurate results in the future.

Peer feedback, therefore, not only improves the quality of the plan, but is also essential for 'teaching' the system. Continuous refinement and feedback

A well-designed process is not a single iteration. As you work, new information, objectives, and external circumstances may change. These changes need to be incorporated into the plans, and the calculations need to be re-run.

The advantage of AI-based systems is that they can react quickly to changes and generate new proposals immediately. However, each refinement has to be followed by a new peer review and feedback.

This "circular" design process ensures that the final design is both economically and technologically optimal and feasible.

Articial Intelligence in the Process Specification

AI assists in finding the parameters of the explosive and fire plate material for the setup parameter determination. AI rapidly finds the data and uses it for calculations. The material selection is interactive because the user must select materials based on the work's goal. AI can suggest solutions, but the final decision needs to be made by the user. Material selection is limited by the rules described above. The parameter limits are included in the application program. AI assists in determining the parameters, and the algorithm of the application is illustrated in Figure 3.

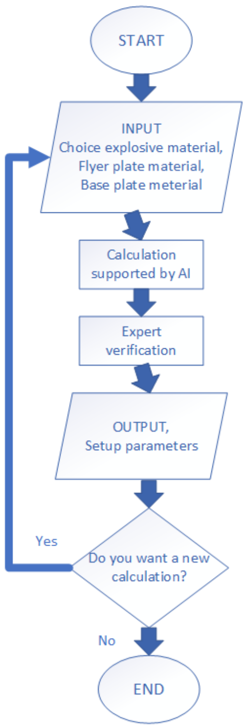

Figure 3. The AI-assisted application algorithm.

Users need to control both the earned results and the AI-suggested results continuously.

CONCLUSIONS

The explosive cladding process is a specialised metal bonding technique that offers several advantages over conventional joining methods. One of its most significant benefits is the ability to create a strong bond between metals that are typically incompatible, such as aluminium and steel. Another notable advantage is that there are practically no limitations regarding the thickness ratio of the metals to be joined, making the process highly versatile for various geometries. Additionally, the method requires only minimal equipment and tooling, making it a cost-effective alternative to traditional welding processes.

Explosive cladding finds applications in several industrial sectors, particularly where special multi-component materials are required. The electrical industry, vehicle manufacturing, and nuclear technology widely utilise this process to produce bi- or multilayered plates, sheets, wires, and other components. Typical applications include bimetallic contact elements in electrical equipment, contacting elements for power transformers, and bonding of superconductors.

Blast welding is a versatile and widely used process in the industry. Unfortunately, in industrial practice, most engineers lack adequate knowledge of explosive welding. The presented application will assist engineers who lack a broad understanding of explosives and blasting specialists who are familiar with explosives but not with welding technology in their technological planning.

The app is a help for engineers, but the responsibility for the technology's suitability lies with the welding technologist. In practice, even with the specified parameters, blast welding should only be carried out under the supervision and with the support of a blasting technician for security reasons.

The introduced AI supported process parameter determination process algorithm shown in Fugure.3. which can demonstrate that Artificial intelligence is nowadays an undoubtedly useful tool in technology parameter deteremination as well in the case on the explosive welding process. It helps engineers to manage data, perform calculations quickly and determine optimal parameters. It makes design work faster, more transparent and more efficient.

At the same time, AI can only be used safely and effectively if designs are accompanied by continuous peer review and feedback. Without engineering knowledge, practical experience and consideration of local specificities, MI proposals alone are not sufficient.

However, if used well and integrated into the design process with appropriate control, AI can become a truly valuable tool for modern engineering practice.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

LITERATURE

Alwazae, M. M., Perjons, E., & Kjellin, H. (2014). Quality measures for documentation of best practices. *In 2014 47th Hawaii International Conference on System Sciences* (pp. 3410-3419). IEEE.

Arbaz, A., Fan, H., Ding, J., Qiu, M., & Feng, Y. (2024). GenFlowchart: parsing and understanding flowchart using generative AI. In *International Conference on Knowledge Science, Engineering and Management* (pp. 99-111). Singapore: Springer Nature Singapore.

ASM Handbook (1992). Welding, Brazing and Soldering. *ASM International*, *6*, USA, pp. 525–537.

Catovic, A. (2020). An overview of the Gurney method for estimating the initial velocity of fragments for high explosive munition. *Defence Secur Stud, 1*(1), 16–28.

Davis, J.R. (2002). Surface Hardening of Steels, *ASM International*, 1-16.

Ejiwale, J. (2014). Facilitating collaboration across science, technology, engineering and mathematics (STEM) fields in program development. *Journal of STEM Education, 15*(2).

Findik, F. (2011). Recent developments in explosive welding. *Mater Des, 32*(3), 1081–1093.

Fucheng, Z., Lv, B., Wang, T., Zheng, C., Zhang, M., Luo, H. H. and Liu, H. (2008). Microstructure and Properties of Purity High Mn Steel Crossing Explosion Hardened, *ISIJ International,* 48, 1766-1770.

Goka, S., Narayana, G. S., Divya Jyothi, G., Shaik, H. S., & Moinuddin, S. Q. (2024). AI and ML in Welding Technologies. Automation in Welding Industry: Incorporating Artificial Intelligence, *Machine Learning and Other Technologies*, 73-90.

Greenberg, B. A., Ivanov, M. A., Kuzmin, S. V., & Lysak, V. I. (2019). Explosive welding: processes and structures. *CRC Press*.

Greenhalgh, T., & Peacock, R. (2005). Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources. *Bmj, 331*(7524), 1064-1065.

Nyikes, Z., & Kovács, T.A. (2025). Artificial Intelligance supported application for explosive cladding process specification. *STED Conference 14*(2), 303-310.

Grønbæk, K., Grudin, J., Bødker, S., & Bannon, L. (2017). Achieving cooperative system design: shifting from a product to a process focus. *In Participatory Design* (pp. 79-97). CRC Press.

Havlícek, P., & Busóvá, K. (2012). Experience with explosive hardening of railway frogs from Hadfield steel, *Metal*, Brno, Czech Republic

Hedman, E. (2015). Facilitating leadership team communication. *Jyväskylä studies in humanities,* (266).

Hirsch, E. (1995). On the inconsistency of the asymmetric-sandwich gurney formula when used to model thin plate propulsion. *Propellants, Explos, Pyrotech, 20*, 178-181

Holtzman A. H., & Cowan G. R. (1965). Bonding of metal with explosives, *Welding Research Council bulletin,* New York. pp. 1-21. https://doi.org/10.1016/j.matdes.2010.10.017

Javaid, M., Haleem, A., Singh, R. P., & Suman, R. (2022). Artificial intelligence applications for industry 4.0: A literature-based study. *Journal of Industrial Integration and Management, 7*(01), 83-111.

Jeon, S. M., & Kim, G. (2016). A survey of simulation modeling techniques in production planning and control (PPC). *Production Planning & Control, 27*(5), 360-377.

Kamaruzaman, F. M., Hamid, R., & Mutalib, A. A. (2017, November). A review on issues and challenges in incorporating complex engineering problems in engineering curriculum and proposed solutions. In 2017 7th *World Engineering Education Forum (WEEF)* (pp. 697-701). IEEE.

Kovács-Coskun, T. (2016) Explosive Surface Hardening of Austenitic Stainless Steel, *IOP Conference Series: Materials Science and Engineering, 123*, 1-5.

Kugyela, L., Daruka, N., & Kovács, T.A. (2024) Explosive Welding of Metals for Electronic Applications in The Impact of the Energy Dependency on Critical Infrastructure Protection, *Advanced Sciences and Technologies for Security Applications,* https://doi.org/10.1007/978-3-031-78544-3_35

Liu, F.C., B. Lv, Zhang, F.C., & Yang, S. (2011) Enhanced work hardening in Hadfield steel during explosive treatment, *Materials letters* 65. Elsevier. pp. 2333-2336.

Lukács, L., Szalay, A., Zádor, I. (2012) Explosive forming and aerospace. *Aeronautical Science Bullettins, XXIV*(2), 431–446.

Meyers, M. A., & Murr, L. E. (1980) Shock Waves and High-Strain-Rate Phenomena in Metals, International Conference on Metallurgical Effects of High-Strain-Rate Deformation and Fabrication, *Albuquerque*, N.M., pp 91-111.

Meyers, M.A., & Murr, L.E. (1980) Shock Waves and High-Strain-Rate Phenomena in Metals, International Conference on Metallurgical Effects of High-Strain-Rate Deformation and Fabrication, *Albuquerque*, N.M.,

Mousavi, A.A.A., & Al-Hassani, S.T.S. (2005) Numerical and experimental studies of the mechanism of the of the wavy interface formations in explosive/impact welding. *J Mech Phys Solids,* 53, 2501-2528.

Patange, G. S., & Pandya, A. B. (2023). How artificial intelligence and machine learning assist in industry 4.0 for mechanical engineers. *Materials Today: Proceedings*, *72*, 622-625.

Perkusich, M., e Silva, L. C., Costa, A., Ramos, F., Saraiva, R., Freire, A., ... & Perkusich, A. (2020). Intelligent software engineering in the context of agile software development: A systematic literature review. *Information and Software Technology*, *119*, 106241.

Peters. N.W. (2005) The performance of Hadfield's manganese steel as it relates manufacture, *Conference Proceedings*, pp. 1-22.

Pival, P. R. (2023). How to incorporate artificial intelligence (AI) into your library workflow. *Library Hi Tech News*, *40*(7), 15-17.

Pocalyko, A. (1964) Explosion clad plate for corrosion service, North Central Region Conference, *National Association of Corrosion Engineers,* Minneapolis, pp. 2-6.

Pocalyko, A. (1981) Metallic Coatings (Explosively Clad), *Encyclopedia of Chemical Technology, 15*, Third edition, pp. 275-296.

Quick, D., & Choo, K. K. R. (2014). Impacts of increasing volume of digital forensic data: A survey and future research challenges. *Digital Investigation*, *11*(4), 273-294.

Nyikes, Z., & Kovács, T.A. (2025). Artificial Intelligance supported application for explosive cladding process specification. *STED Conference 14*(2), 303-310.

Rios, V. S., Avansi, G. D., & Schiozer, D. J. (2020). Practical workflow to improve numerical performance in time-consuming reservoir simulation models using submodels and shorter period of time. *Journal of Petroleum Science and Engineering,* 195, 107547.

Rios, V. S., Avansi, G. D., & Schiozer, D. J. (2020). Practical workflow to improve numerical performance in time-consuming reservoir simulation models using submodels and shorter period of time. *Journal of Petroleum Science and Engineering*, *195*, 107547.

Sadeghi-Bazargani, H., Bangdiwala, S. I., Mohammad, K., Maghsoudi, H., & Mohammadi, R. (2011). Compared application of the new OPLS-DA statistical model versus partial least squares regression to manage large numbers of variables in an injury case-control study. *Sci Res Essays, 6*(20), 4369-4377.

Standley, T. (2010, July). Finding optimal solutions to cooperative pathfinding problems. In *Proceedings of the AAAI conference on artificial intelligence, 24*(1), 173-178.

Staudhammer, K.P., Frantz, C.E., & Hecker, S.S., (1981) Shock Waves and High Strain Rate Phenomena in Metals*, Plenum*, in M.A. Meyers and L.E. Murr (eds.), New York, pp 91-l12

Wasserman, A. I. (2010, November). Software engineering issues for mobile application development. In *Proceedings of the FSE/SDP workshop on Future of software engineering research* (pp. 397-400).

Weman, K. (2011). Welding processes handbook. *Elsevier.*

Whitfield, C. A., Freuler, R. J., Allam, Y., & Riter, E. A. (2011, August). An overview of highly successful first-year engineering cornerstone design projects. In *Proceedings of the 2011 International Conference on Engineering Education* (pp. 21-26).

Zhang, F.C., Yang, Z.N., Qian, L-H., Liu, F.C., Lv, B., & Zhang, M. (2011) High speed bounding: A novel technique for the preparation of a thick surface layer with a hardness gradient distribution on Hadfield steel, *Scipta Materialia 64*, pp.560-563

Zhang, M., Zhang, B.Lv,F., & Feng, X. (2012) Explosion Deformation and Hardening Behaviours of Hadfield Steel Crossing, *ISIJ International*, 52(11), pp. 2093–2095.

Zhou, Z. H. (2021). Machine learning. *Springer nature.*