Journal of Simulation and Analysis of Novel Technologies in Mechanical Engineering
13 (4) (2021) 0041~0051
HTTP://JSME.IAUKHSH.AC.IR

Research article

A new approach using Machine Learning and Deep Learning for the prediction of cancer tumor

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(Manuscript Received --- 6 Feb. 2022; Revised --- 03 Apr. 2022; Accepted --- 16 Apr. 2022)

Abstract

Cancer is now one of the leading causes of death in the world. Existing therapies such as chemotherapy, radiation therapy and other methods due to the effect on other parts and even some side effects are irreversible. On the other hand, the development of nanotechnology to the treatment of cancer has been used in various fields especially drug delivery and diagnostic and imaging cases. Because of their similarity to biological molecules, nanoparticles can easily enter cells and receive much attention when it comes to drug delivery to target tissues. Also, the best and effective solution for treatment is the use of multidisciplinary approaches, and on the other hand, one of the challenges in medical image recognition methods is the problem of dense tissue analysis and the time-consuming process of diagnosis which has caused machine learning and deep learning to receive much attention. Deep learning techniques use data stored in electronic health systems files and process large amounts of resources such as medical imaging and artificial neural networks to help physicians analyze information and diagnose multiple diseases.

Keywords: *Machine learning; Deep learning; Nanoparticles; Medical equipment; Thermotherapy.*

1- Introduction

Cancer is the uncontrolled growth of cells in the body. In a healthy body, there are thousands of billions of cells that divide according to the body's needs [1-4]. Healthy cells have life cycle, reproduction and death depending on their type. As damaged cells die, they are replaced by new cells. Cancer interferes with this very process and causes abnormal growth of cells in the body. When cells divide uncontrollably, they form masses called tumors [5-8]. This disease is the most common cause of death among people in society. There are many treatments such as chemotherapy, radiotherapy and photodynamic therapy which suppresses cancer cell proliferation, shrink tumor size, progression and metastasis, but the drugs used in this method not only damage cancer cells but also healthy tissues and cause side effects [9-14]. Also, about 85% of patients need treatment with new methods that maintain and improve the effectiveness of

chemotherapy while reducing the severity of reactions and side effects [15-22]. Nanotechnology and nanoparticles are used in various fields due to their compatibility with different biological properties, which in the case of cancer also provide a safer and more effective means of chemotherapy and lead to further advances in diagnosis, treatment and imaging. Nanoparticles that have special properties in the treatment and diagnosis of cancer cells include calcium phosphate, gold, metal oxides and transocytic nanoparticles [23-36]. It is worth mentioning that before treatment, diagnosis and especially correct and timely diagnosis of cancer is one of the most important parts of the fight against cancer. Nowadays, artificial intelligence and deep learning (DL) have improved the amount of accurate, correct diagnosis and the time required for diagnosis [37-41].

2- Nanoparticle treatment

Nanoparticles have a diameter of between 1 and 100 (nm), but in some cases for larger particles, up to 500 nm or fibers and tubes that are less than 100 nm are also used. Nanoparticles are usually distinguished from micro particles (1–1000) and coarse particles (from 2,500 to 10,000 nm) because of their different physical and chemical properties [42-51]. For example, colloidal and optical properties created by smaller sizes. As mentioned, magnetic nanoparticles (MNPs) are used in various fields, one of which is medicine. MNPs used in medicine are classified into two main groups. Particles whose main building material is organic molecules that include carbon nanotubes, emulsions, solid lipid nanoparticles, liposomes, dendrimers, aptamers and other polymers, and the second group consists of nanoparticles that usually contain metals and minerals are the core. These nanoparticles are tools for the diagnosis and treatment of diseases such as cancer. Aptamers are peptide and oligonucleotide molecules (RNA or DNA) that bind to small biomolecules, proteins and even cells with a high affinity and specificity. Dendrimers can be used as a factor to detect various pathological processes and also as a contrast agent in MRI. Liposomes can also be used for transmission in chemotherapy of various tumors in humans. Most mineral nanoparticles have an organic protective coating on the surface and a central core with electrical, fluorescence, and magnetic properties [52-57]. This outer layer can bind to positively charged molecules and biomolecules containing amine or thiol groups by covalent or electrostatic bonding, thus protecting the central part from environmental degrading agents. Ultra-magnetic nanoparticles are used to increase contrast and are used in MRI. Also, a special type of drug is used in the treatment of cancer [58-62]. It is worth mentioning that this group of nanoparticles is also used in gene expression, angiogenesis, cell traffic, etc.

3- Nanoparticles and imaging and treatment

By conjugating nanoparticles with targeted antibodies with the help of biotin and streptoavidin, cancer can be diagnosed and treated simultaneously. This method is used to form a nanoshell by conjugating an ERBB2 antibody to a modified metal nanoparticle; the nanoshell consists of a spherical nanoparticle in the dielectric core consisting of silica and surrounded by a thin crust or shell of gold [63-37]. The nano-shell converts light into heat due to the proximity of the emission spectrum to infrared and acts thermally in tumor surgery

or tumor removal. The heat generated is too much to cause irreversible tissue damage and therefore causes cell death. Also, the efficiency of these nanoparticles, which generate heat under the influence of near-IR radiation, is one million times more efficient than that of color molecules.

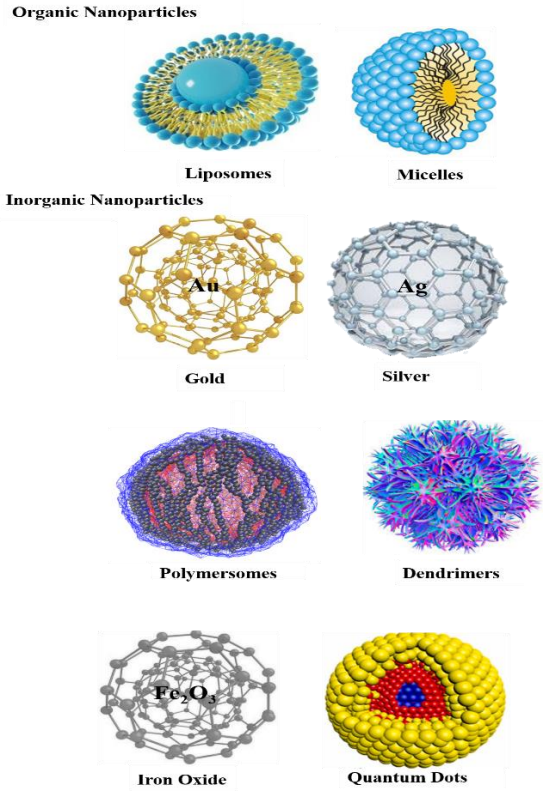

Fig. 1 Types of nanoparticles used in drug delivery system to treat cancer

4- Nanoparticles and cervical cancer

Cervical cancer is a preventable and easily diagnosed disease, however it is one of the three malignant cancers in women and the leading cause of death among women [7]. This test examines for the presence of cancerous or precancerous cells in the cervix. In this test, the cervical cells are gently removed and examined for abnormal growth. Conventional cancer treatments cause disability in the patient. Therefore, scientists are looking for a new way to treat this cancer; one of these methods is to use gold nanoparticles as carriers to deliver the hydrophobic protoporphine molecule into the cancer cell. Gold nanoparticles have the ability to bind strongly to molecules. On the other hand, porphyrins and tetrapyrrole compounds have received much attention due to their wide biological importance and physical, chemical and spectroscopic properties. In addition, these compounds are widely used as optical sensitizers, selective placement in tumor cells, and because they are non-toxic in the treatment of cancer.

According to research, a new treatment for cancer as well as cervical cancer can be developed by designing gold nanoparticles conjugated with protoporphyrin photosensors [68-71]. In this method, gold nanoparticles are coupled to protoporphyrin IX (PpIX) to make gold nanoparticles with an average diameter of about seven nanometers. The results of this study show that these synthesized conjugated gold nanoparticles can be used to treat cervical cancer cells as a highly effective drug carrier to deliver photosensitizers into cells.

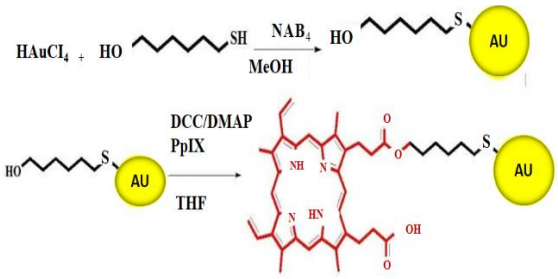

Fig. 2 Synthesis of protoporphyrin-conjugated gold nanoparticles

5- Artificial intelligence in medicine and cancer diagnosis

DL is a subset of machine learning that uses more complex concepts than machine learning algorithms. DL works with neural networks. These networks are designed to mimic human thinking and learning. Until recently, neural networks had limited

computational power and were not very sophisticated. However, advances in big data analytics have allowed larger and more sophisticated neural networks to allow computers to observe, learn, and respond faster than humans. DL has many applications in image classification, language translation and speech recognition; it can also identify patterns for solving any problem and do things without human intervention. Artificial neural networks that cover many layers guide deep learning. These deep neural networks (DNNs) are a type of network, each layer of which performs complex operations such as display and abstract thinking, which helps to make images, sounds and text meaningful. As mentioned, deep learning is one of the sub-fields of machine learning that is widely used in the field of artificial intelligence. DL techniques use data stored in the records of electronic health systems and process large amounts of resources from various sources such as medical imaging, artificial neural networks that help physicians analyze information and diagnose multiple diseases. It performs the diagnosis automatically [68-71]. Information analysis such as blood samples, glucose monitoring in diabetics, diagnosis of heart problems, image analysis to diagnose tumors, cancer cells and cancer, diagnosis of osteoarthritis by MRI before the onset of injury. This is to address many of the concerns of medical care used to reduce the rate of misdiagnosis and predict the outcome of steps. Some of the most important applications of artificial intelligence in medicine.

Due to the importance of brain tissues and cells, the use of computational techniques such as predictive modeling and machine learning including processing and diagnosis of medical images, accurate tumor location detection and radiotherapy response prediction Increases the accuracy of radiotherapy and reduces damage to healthy tissues around the tumor. To find the best model for analyzing cancer data, regression analysis including: linear regression and ordinary least squares regression or OLS and logistic regression can be used. Knowledge-based decision support systems are used to improve clinical decision making, and artificial neural networks and fuzzy logic are used to better and faster predict brain cancer. A team of researchers has also developed a mathematical model for classifying brain tumors. This model can identify brain tumors and classify them into one of six categories [66-71]. This model uses only a three-dimensional MRI image. It is also the first study of common intracranial tumors to determine the presence or absence of tumors based on three-dimensional MRI and mechanical imaging. In addition, it has the potential to automate the diagnosis and classification of brain tumors [68-71]. This product analyzed large amounts of data to determine the best treatment options for patients with tumors with genetic abnormalities. This acts as a way to prevent readmission as well as reduce the length of time patients are hospitalized [66-71]. Artificial intelligence is also used to diagnose low back pain. A team of researchers at Mount Sinai University has developed a type of artificial intelligence that can study patients' medical records to diagnose low back pain and determine whether it is chronic or acute. Using this technology, the patient can be told when to return to normal activities, how long to rest, or how many times to see a doctor. This research is also used to discuss the diagnosis, treatment, coding, and reporting of other musculoskeletal disorders

such as knee pain, elbow pain, and shoulder pain.

6- Deep learning and cervical cancer

One of the most important DNN methods is the Convolutional Neural Network (CNN). These networks are multilayer neural networks designed for two-dimensional data such as images. The structure of CNN generally consists of two parts. The first part is the extraction of image properties, which is obtained from the input image by the layers of Convolution, pooling, etc. The second part contains a Fully connected neural network (meaning that all neurons are connected to the next) that can use the multilayer perceptron neural network. To begin with, the input images to the CNNs are converted to RGB format and then into the first Convolutional layer; each layer of Convolutional has neurons that each neuron in a CNN is considered as a filter that scans an image for a specific feature. These feature maps are routed forward and each is used as an input for filters in the next layer [68-71]. To build an overall understanding of the features of an image and measure its compatibility with the CNN format for a particular object this process continues and finally one layer sends its output to one or more fully connected layers. Also, the more layers are used, the more features the extraction will bring, and by adding filters, it may pay more attention to more precise details.

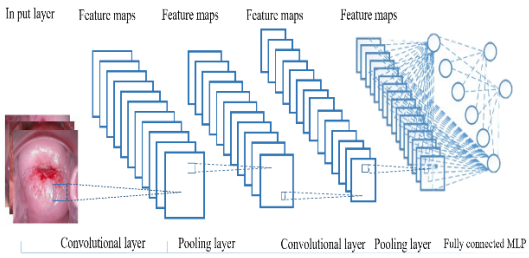

Fig. 3 A simple view from CNN

To apply this science to the diagnosis of cervical cancer, approximately one hundred thousand images of the cervix are used, which are classified into categories such as healthy tissue, benign inflammation, precancerous lesions and suspected cancer. After defining the CNN architecture, Caffe software, which is responsible for validating and training CNN, adjusts CNN filters to improve overall system accuracy. In order for the intelligent system to understand the incompatibilities, the effects of light and magnification, and the changes that occur when taking photos with a mobile device, the system is trained and the diagnoses and performance of the smart device will be compared and evaluated with the diagnosis of medical specialists and pathology tests in the laboratory during testing [66-71].

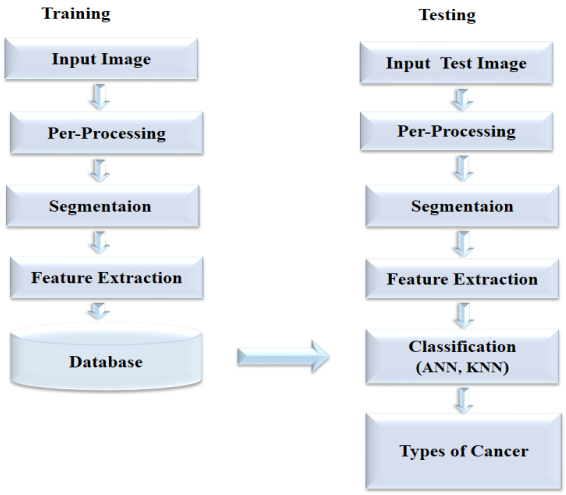

Fig. 4 Block diagram of the proposed system for the diagnosis of cervical cancer

7- Conclusion

As mentioned, cancer is one of the leading causes of death in the world and the number of cancer patients is increasing day by day. Therefore, a lot of attention has been paid to finding a way to diagnose, especially early diagnosis, when there is a good time for treatment before the cancer metastasizes, as well as treatment. In fact, there are

treatments such as chemotherapy, radiation therapy and radiotherapy, but due to the effects that exist during and after treatment. In addition, some cancers that are resistant to these methods have led researchers to develop a new method. On the other hand, effective and the best solution for treatment is the use of multidisciplinary approaches. Therefore, it is possible to use different methods and tools such as the use of nanoparticles for specific delivery of cancer drugs to target tissues and reduce damage to other parts of tissues and organs of the body or the use of nanoparticles to as a method of treatment, as well as the use of deep learning for timely, accurate and correct diagnosis, in addition to saving time and money, unwanted biological effects can be minimized.

References

[1] Delaney, G., Jacob, S., Featherstone, C., & Barton, M. (2005). The role of radiotherapy in cancer treatment: estimating optimal utilization from a review of evidence-based clinical guidelines. Cancer: Interdisciplinary International Journal of the American Cancer Society, 104(6), 1129-1137.

[2] Sodickson, A., Baeyens, P.F., Andriole, K.P., Prevedello, L.M., Nawfel, R.D., Hanson, R. and Khorasani, R., (2009). Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. Radiology, 251(1), pp. 175-184.

[3] Lambin, Philippe, et al. "Radiomics: extracting more information from medical images using advanced feature analysis." European journal of cancer 48.4 (2012): 441-446.

[4] Sanvicens, Nuria, and M. Pilar Marco. "Multifunctional nanoparticles–properties and prospects for their use in human medicine." Trends in biotechnology 26, no. 8 (2008): 425-433.

[5] Fass, L., 2008. Imaging and cancer: a review. Molecular oncology, 2(2), pp. 115-152.

[6] Weissleder R. Scaling down imaging: molecular mapping of cancer in mice. Nature Reviews Cancer. 2002 Jan;2(1):11-8.

[7] Lee, C.H., Dershaw, D.D., Kopans, D., Evans, P., Monsees, B., Monticciolo, D., Brenner, R.J., Bassett, L., Berg, W., Feig, S. and Hendrick, E., 2010. Breast cancer screening with imaging: recommendations from the Society of Breast Imaging and the ACR on the use of mammography, breast MRI, breast ultrasound, and other technologies for the detection of clinically occult breast cancer. Journal of the American college of radiology, 7(1), pp.18-27.

[8] Stupp, R., Taillibert, S., Kanner, A. A., Kesari, S., Steinberg, D. M., Toms, S. A., ... & Ram, Z. (2015). Maintenance therapy with tumor-treating fields plus temozolomide vs temozolomide alone for glioblastoma: a randomized clinical trial. Jama, 314(23), 2535-2543.

[9] Ron, Elaine, Baruch Modan, John D. Boice Jr, Esther Alfandary, Marilyn Stovall, Angela Chetrit, and Leah Katz. "Tumors of the brain and nervous system after radiotherapy in childhood." New England Journal of Medicine 319, no. 16 (1988): 1033-1039.

[10] Keall, P.J., Mageras, G.S., Balter, J.M., Emery, R.S., Forster, K.M., Jiang, S.B., Kapatoes, J.M., Low, D.A., Murphy, M.J., Murray, B.R. and

Ramsey, C.R., (2006). The management of respiratory motion in radiation oncology report of AAPM Task Group 76 a. medical physics, 33(10), pp. 3874-3900.

[11] Amis Jr, E. Stephen, et al. "American College of Radiology white paper on radiation dose in medicine." Journal of the American college of radiology 4.5 (2007): 272-284.

[12] Khandan, A., Abdellahi, M., Ozada, N., & Ghayour, H. (2016). Study of the bioactivity, wettability and hardness behaviour of the bovine hydroxyapatite-diopside bio-nanocomposite coating. *Journal of the Taiwan Institute of Chemical Engineers*, *60*, 538-546.

[13] Karamian, E., Motamedi, M. R. K., Khandan, A., Soltani, P., & Maghsoudi, S. (2014). An in vitro evaluation of novel NHA/zircon plasma coating on 316L stainless steel dental implant. *Progress in Natural Science: Materials International*, *24*(2), 150-156.

[14] Karamian, E., Abdellahi, M., Khandan, A., & Abdellah, S. (2016). Introducing the fluorine doped natural hydroxyapatite-titania nanobiocomposite ceramic. *Journal of Alloys and Compounds*, *679*, 375-383.

[15] Najafinezhad, A., Abdellahi, M., Ghayour, H., Soheily, A., Chami, A., & Khandan, A. (2017). A comparative study on the synthesis mechanism, bioactivity and mechanical properties of three silicate bioceramics. *Materials Science and Engineering: C*, *72*, 259-267.

[16] Ghayour, H., Abdellahi, M., Ozada, N., Jabbrzare, S., & Khandan, A. (2017). Hyperthermia application of zinc doped nickel ferrite nanoparticles. *Journal of Physics and Chemistry of Solids*, *111*, 464-472.

[17] Kazemi, A., Abdellahi, M., Khajeh-Sharafabadi, A., Khandan, A., & Ozada, N. (2017). Study of in vitro bioactivity and mechanical properties of diopside nano-bioceramic synthesized by a facile method using eggshell as raw material. *Materials Science and Engineering: C*, *71*, 604-610.

[18] Khandan, A., & Ozada, N. (2017). Bredigite-Magnetite (Ca7MgSi4O16-Fe3O4) nanoparticles: A study on their magnetic properties. *Journal of Alloys and Compounds*, *726*, 729-736.

[19] Khandan, A., Jazayeri, H., Fahmy, M. D., & Razavi, M. (2017). Hydrogels: Types, structure, properties, and applications. *Biomat Tiss Eng*, *4*(27), 143-69.

[20] Sharafabadi, A. K., Abdellahi, M., Kazemi, A., Khandan, A., & Ozada, N. (2017). A novel and economical route for synthesizing akermanite (Ca2MgSi2O7) nano-bioceramic. *Materials Science and Engineering: C*, *71*, 1072-1078.

[21] Khandan, A., Abdellahi, M., Ozada, N., & Ghayour, H. (2016). Study of the bioactivity, wettability and hardness behaviour of the bovine hydroxyapatite-diopside bio-nanocomposite coating. *Journal of the Taiwan Institute of Chemical Engineers*, *60*, 538-546.

[22] Shayan, A., Abdellahi, M., Shahmohammadian, F., Jabbarzare, S., Khandan, A., & Ghayour, H. (2017). Mechanochemically aided sintering process for the synthesis of barium ferrite: Effect of aluminum substitution on microstructure, magnetic properties and microwave absorption. *Journal of Alloys and Compounds*, *708*, 538-546

[23] Heydary, H. A., Karamian, E., Poorazizi, E., Khandan, A., &

Heydaripour, J. (2015). A novel nano-fiber of Iranian gum tragacanth-polyvinyl alcohol/nanoclay composite for wound healing applications. *Procedia Materials Science*, *11*, 176-182.

[24] Khandan, A., Karamian, E., & Bonakdarchian, M. (2014). Mechanochemical synthesis evaluation of nanocrystalline bone-derived bioceramic powder using for bone tissue engineering. *Dental Hypotheses*, *5*(4), 155.

[25] Karamian, E., Khandan, A., Kalantar Motamedi, M. R., & Mirmohammadi, H. (2014). Surface characteristics and bioactivity of a novel natural HA/zircon nanocomposite coated on dental implants. *BioMed research international*, *2014*.

[26] Jabbarzare, S., Abdellahi, M., Ghayour, H., Arpanahi, A., & Khandan, A. (2017). A study on the synthesis and magnetic properties of the cerium ferrite ceramic. *Journal of Alloys and Compounds*, *694*, 800-807.

[27] Razavi, M., & Khandan, A. (2017). Safety, regulatory issues, long-term biotoxicity, and the processing environment. In *Nanobiomaterials Science, Development and Evaluation* (pp. 261-279). Woodhead Publishing.

[28] Khandan, A., Ozada, N., & Karamian, E. (2015). Novel microstructure mechanical activated nano composites for tissue engineering applications. *J Bioeng Biomed Sci*, *5*(1), 1.

[29] Ghayour, H., Abdellahi, M., Bahmanpour, M., & Khandan, A. (2016). Simulation of dielectric behavior in RFeO $$ _ {3} $$3 orthoferrite ceramics (R= rare earth metals). *Journal of Computational Electronics*, *15*(4), 1275-1283.

[30] Saeedi, M., Abdellahi, M., Rahimi, A., & Khandan, A. (2016). Preparation and characterization of nanocrystalline barium ferrite ceramic. *Functional Materials Letters*, *9*(05), 1650068.

[31] Khandan, A., Karamian, E., Faghih, M., & Bataille, A. (2014). Formation of AlN Nano Particles Precipitated in St-14 Low Carbon Steel by Micro and Nanoscopic Observations. Journal of Iron and Steel Research International, 21(9), 886-890.

[32] Karamian, E. B., Motamedi, M. R., Mirmohammadi, K., Soltani, P. A., & Khandan, A. M. (2014). Correlation between crystallographic parameters and biodegradation rate of natural hydroxyapatite in physiological solutions. Indian J Sci Res, 4(3), 092-9.

[33] Khandan, A., & Esmaeili, S. (2019). Fabrication of polycaprolactone and polylactic acid shapeless scaffolds via fused deposition modelling technology. Journal of Advanced Materials and Processing, 7(4), 16-29.

[34] Fang, Y., Bokov, D. O., Hachem, K., Sabetvand, R., Alsultany, F. H., Suksatan, W., ... & Toghraie, D. (2022). The computational investigation of thermal conductivity of 11S globulin protein for biological applications: Molecular dynamics simulation. Journal of Molecular Liquids, 346, 118267.

[35] Toghraie Semiromi, D., & Azimian, A. R. (2010). Nanoscale Poiseuille flow and effects of modified Lennard–Jones potential function. Heat and mass transfer, 46(7), 791-801.

[36] Semiromi, D. T., & Azimian, A. R. (2011). Molecular dynamics simulation of nonodroplets with the modified

Lennard-Jones potential function. Heat and mass transfer, 47(5), 579-588.

[37] Toghraie Semironi, D., & Azimian, A. R. (2010). Molecular dynamics simulation of liquid–vapor phase equilibrium by using the modified Lennard-Jones potential function. Heat and mass transfer, 46(3), 287-294.

[38] Noorian, H., Toghraie, D., & Azimian, A. R. (2014). The effects of surface roughness geometry of flow undergoing Poiseuille flow by molecular dynamics simulation. Heat and Mass Transfer, 50(1), 95-104.

[39] Semiromi, D. T., & Azimian, A. R. (2012). Molecular dynamics simulation of annular flow boiling with the modified Lennard-Jones potential function. Heat and Mass Transfer, 48(1), 141-152.

[40] Oveissi, S., Eftekhari, S. A., & Toghraie, D. (2016). Longitudinal vibration and instabilities of carbon nanotubes conveying fluid considering size effects of nanoflow and nanostructure. Physica E: Low-dimensional Systems and Nanostructures, 83, 164-173.

[41] Saeedi, M. R., Morovvati, M. R., & Mollaei-Dariani, B. (2020). Experimental and numerical investigation of impact resistance of aluminum–copper cladded sheets using an energy-based damage model. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 42(6), 1-24.

[42] Kardan-Halvaei, M., Morovvati, M. R., & Mollaei-Dariani, B. (2020). Crystal plasticity finite element simulation and experimental investigation of the micro-upsetting process of OFHC copper. Journal of Micromechanics and Microengineering, 30(7), 075005.

[43] Fazlollahi, M., Morovvati, M. R., & Mollaei Dariani, B. (2019). Theoretical, numerical and experimental investigation of hydro-mechanical deep drawing of steel/polymer/steel sandwich sheets. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 233(5), 1529-1546.

[44] Saeedi, M. R., Morovvati, M. R., & Alizadeh-Vaghasloo, Y. (2018). Experimental and numerical study of mode-I and mixed-mode fracture of ductile U-notched functionally graded materials. International Journal of Mechanical Sciences, 144, 324-340.

[45] Morovvati, M. R., & Mollaei-Dariani, B. (2018). The formability investigation of CNT-reinforced aluminum nano-composite sheets manufactured by accumulative roll bonding. The International Journal of Advanced Manufacturing Technology, 95(9), 3523-3533.

[46] Morovvati, M. R., & Dariani, B. M. (2017). The effect of annealing on the formability of aluminum 1200 after accumulative roll bonding. Journal of Manufacturing Processes, 30, 241-254.

[47] Morovvati, M. R., Lalehpour, A., & Esmaeilzare, A. (2016). Effect of nano/micro B4C and SiC particles on fracture properties of aluminum 7075 particulate composites under chevron-notch plane strain fracture toughness test. Materials Research Express, 3(12), 125026.

[48] Fatemi, A., Morovvati, M. R., & Biglari, F. R. (2013). The effect of tube material, microstructure, and heat treatment on process responses of tube hydroforming without axial force. The International Journal of Advanced

Manufacturing Technology, 68(1), 263-276.

[49] Pourmoghadam, M. N., Esfahani, R. S., Morovvati, M. R., & Rizi, B. N. (2013). Bifurcation analysis of plastic wrinkling formation for anisotropic laminated sheets (AA2024–Polyamide–AA2024). Computational materials science, 77, 35-43.

[50] Morovvati, M. R., Mollaei-Dariani, B., & Haddadzadeh, M. (2010). Initial blank optimization in multilayer deep drawing process using GONNS. Journal of manufacturing science and engineering, 132(6).

[51] Fatemi, A., Biglari, F., & Morovvati, M. R. (2010). Influences of inner pressure and tube thickness on process responses of hydroforming copper tubes without axial force. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 224(12), 1866-1878.

[52] Anarestani, S. S., Morovvati, M. R., & Vaghasloo, Y. A. (2015). Influence of anisotropy and lubrication on wrinkling of circular plates using bifurcation theory. International Journal of Material Forming, 8(3), 439-454.

[53] Talebi, M., Abbasi-Rad, S., Malekzadeh, M., Shahgholi, M., Ardakani, A. A., Foudeh, K., & Rad, H. S. (2021). Cortical bone mechanical assessment via free water relaxometry at 3 T. *Journal of Magnetic Resonance Imaging*, *54*(6), 1744-1751.

[54] Lucchini, R., Carnelli, D., Gastaldi, D., Shahgholi, M., Contro, R., & Vena, P. (2012). A damage model to simulate nanoindentation tests of lamellar bone at multiple penetration depth. In *6th European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS 2012* (pp. 5919-5924).

[55] SHAHGHOLI GHAHFAROKHI, M. O. H. A. M. A. D. (2014). Experimental and numerical characterization of native bone tissue and glass ceramic bone scaffold at small scale.

[56] Fada, R., Farhadi Babadi, N., Azimi, R., Karimian, M., & Shahgholi, M. (2021). Mechanical properties improvement and bone regeneration of calcium phosphate bone cement, Polymethyl methacrylate and glass ionomer. *Journal of Nanoanalysis*, *8*(1), 60-79.

[57] Monfared, R. M., Ayatollahi, M. R., & Isfahani, R. B. (2018). Synergistic effects of hybrid MWCNT/nanosilica on the tensile and tribological properties of woven carbon fabric epoxy composites. *Theoretical and Applied Fracture Mechanics*, *96*, 272-284.

[58] Ayatollahi, M. R., Barbaz Isfahani, R., & Moghimi Monfared, R. (2017). Effects of multi-walled carbon nanotube and nanosilica on tensile properties of woven carbon fabric-reinforced epoxy composites fabricated using VARIM. *Journal of Composite Materials*, *51*(30), 4177-4188.

[59] Kamarian, S., Bodaghi, M., Isfahani, R. B., Shakeri, M., & Yas, M. H. (2021). Influence of carbon nanotubes on thermal expansion coefficient and thermal buckling of polymer composite plates: Experimental and numerical investigations. *Mechanics Based Design of Structures and Machines*, *49*(2), 217-232.

[60] Ayatollahi, M. R., Moghimi Monfared, R., & Barbaz Isfahani, R. (2019). Experimental investigation on tribological properties of carbon fabric

composites: effects of carbon nanotubes and nano-silica. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, *233*(5), 874-884.

[61] Kamarian, S., Bodaghi, M., Isfahani, R. B., & Song, J. I. (2020). A comparison between the effects of shape memory alloys and carbon nanotubes on the thermal buckling of laminated composite beams. *Mechanics Based Design of Structures and Machines*, 1-24.

[62] Mirsasaani, S. S., Bahrami, M., & Hemati, M. (2016). Effect of Argon laser Power Density and Filler content on Physico-mechanical properties of Dental nanocomposites. *Bull. Env. Pharmacol. Life Sci*, *5*, 28-36.

[63] Ghomi, F., Daliri, M., Godarzi, V., & Hemati, M. (2021). A novel investigation on characterization of bioactive glass cement and chitosan-gelatin membrane for jawbone tissue engineering. *Journal of Nanoanalysis*.

[64] Mirsasaani, S. S., Hemati, M., Dehkord, E. S., Yazdi, G. T., & Poshtiri, D. A. (2019). Nanotechnology and nanobiomaterials in dentistry. In *Nanobiomaterials in clinical dentistry* (pp. 19-37). Elsevier.

[65] Mahale, R. S., Shamanth, V., Sharath, P. C., Shashanka, R., & Hemanth, K. (2021). A review on spark plasma sintering of duplex stainless steels. *Materials Today: Proceedings*, *45*, 138-144.

[66] Chaudhari, V., Bodkhe, V., Deokate, S., Mali, B., & Mahale, R. (2019). Parametric optimization of TIG welding on SS 304 and MS using Taguchi approach. *Int. Res. J. Eng. Technol*, *6*(5), 880-885.

[67] Kamble, P., & Mahale, R. (2016). Simulation and parametric study of clinched joint. *Int Res J Eng Technol*, *3*(05), 2730-2734.

[68] Patil, A., Banapurmath, N., Hunashyal, A. M., Meti, V., & Mahale, R. (2022). Development and Performance analysis of Novel Cast AA7076-Graphene Amine-Carbon Fiber Hybrid Nanocomposites for Structural Applications. *Biointerface Research in Applied Chemistry*, *12*(2), 1480-1489.

[69] Yadav, R. R., More, S. S., Mutekar, O. N., Mogal, A. L., & Mahale, R. S. (2019). Multilevel object sorting system using PLC controller. *Int Res J Eng Technol (IRJET)*, *6*(05), 1910.

[70] Ravishankar, S., & Mahale, R. (2015). A study on magneto rheological fluids and their applications. *International Research Journal of Engineering and Technology*, *2*, 2023-2028.

[71] Nithin, S. K., Hemanth, K., Shamanth, V., Mahale, R. S., Sharath, P. C., & Patil, A. (2021). Importance of condition monitoring in mechanical domain. *Materials Today: Proceedings*.