A stress destruction stage field model on behalf of hydrofracturing of crawling ice shelves and glaciers

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ABSTRACT

There is a need for computational models capable of predicting meltwater-assisted crevasse growth in glacial ice. Mass loss from glaciers and ice sheets is the largest contributor to sea- level rise and iceberg calving due to hydrofracture is one of the most prominent yet less understood glacial mass loss processes. To overcome the limitations of empirical and analytical approaches, we here propose a new phase field-based computational framework to simulate crevasse growth in both grounded ice sheets and floating ice shelves. The model incorporates the three elements needed to mechanistically simulate hydrofracture of surface and basal crevasses: (i) a constitutive description incorporating the non-linear viscous rheology of ice, (ii) a phase field formulation capable of capturing cracking phenomena of arbitrary complexity, such as 3D crevasse interaction, and (iii) a poro-damage representation to account for the role of meltwater pressure on crevasse growth. A stress-based phase field model is adopted to reduce the length- scale sensitivity, as needed to tackle the large scales of iceberg calving, and to adequately predict crevasse growth in tensile stress regions of incompressible solids. The potential of the computational framework presented is demonstrated by addressing a number of 2D and 3D case studies, involving single and multiple crevasses, and considering both grounded and floating conditions. The model results show a good agreement with analytical approaches when particularised to the idealised scenarios where these are relevant. More importantly, we demonstrate how the model can be used to provide the first computational predictions of crevasse interactions in floating ice shelves and 3D ice sheets, shedding new light into these phenomena. Also, the creep-assisted nucleation and growth of crevasses is simulated in a realistic geometry, corresponding to the Helheim glacier. The computational framework presented opens new horizons in the modelling of iceberg calving and, due to its ability to incorporate incompressible behaviour, can be readily incorporated into numerical ice sheet models for projecting sea-level rise.

KEYWORDS: Fracture Mechanics, Structural Integrity, Hydrogen Embrittlement, Nondestructive Evaluation

1.0 INTRODUCTION

Ice sheets are large masses of glacial ice that inundate the surrounding landscape in Greenland and Antarctica today, and many other regions during ice ages [1-23]. These act as enormous stores of freshwater – containing approximately 70% of the planet's supply [24-38] – that assist in regulating a stable global climate, through maintaining global ocean-water levels and controlling surface temperatures by reflecting solar radiation due to its high albedo properties [39-47]. Ice sheets thin toward their margins, and if these are located in marine settings, they will form floating extensions known as ice shelves, which act to provide resistive buttressing to downslope flow and reduce the flux of grounded ice to the ocean. However, increasing global temperatures as a result of carbon emissions has lead to higher rates of ablation than accumulation, resulting in ice shelf and ice sheet thinning in some key areas where ice-sheet instability may follow [48-65]. Surface and basal crevasses can form within ice sheets as a consequence of ongoing deformations within the ice. These are deep crack-like defects that can propagate in an unstable manner and lead to large-scale iceberg calving events, and in extreme cases the catastrophic break up of ice shelves. The frequency of these events has grown in recent decades, beginning with the disintegration of Larsen A (1995) and Larsen B (2002) ice shelves, and more recently significant surface melting and iceberg calving on Larsen C (2017), Pine Island and Thwaites (2018–2020), and Conger (2022) ice shelves [66-79]. Fracture within ice shelves can result in a loss of resistance to down slope glacial flow, leading to ice-sheet thinning, additional flotation of grounded ice and, thus, potentially irreversible grounding line retreats [1-19]. Deposition of grounded glacial ice into the ocean is one of the leading contributors to sea level rise [20-34], having direct implications within this Century on low-lying coastal regions through flooding, increased extreme environmental events, degradation of farmland and loss of habitat, among others. A key driving factor for their stability is the production of surface meltwater as a result of elevated surface temperatures [35-49]. When ice shelves and glaciers melt, meltwater flows down-slope into surface crevasses, causing additional tensile stresses to form within the crevasse. This leads to crevasse instability, and with sufficient meltwater, the crevasse can propagate through the full thickness of the ice column. This process is generally referred to in the glaciological literature as hydrofracture [50-67]. A recent study by Lai et al. found that approximately 60 ± 10% of Antarctic ice shelves provide significant buttressing to downslope flow and are vulnerable to meltwater driven hydrofracture, highlighting the significance of studying the formation and propagation of crevasses in glaciers [68-79]. An illustration of a grounded ice sheet, transitioning to a crevassed floating ice shelf is shown in Fig. 1.

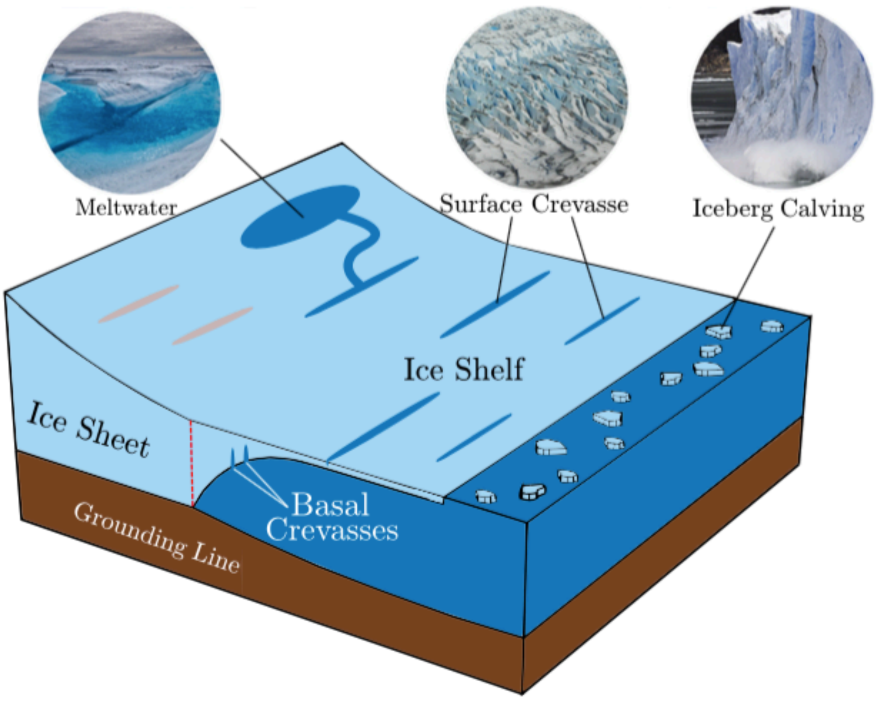

Fig. 1. Illustration of a grounded ice sheet and a floating ice shelf, containing both surface and basal crevasses, and with calving events occurring at the terminus.

integrating over the crevasse depth for the normal tensile stress, the lithostatic compressive stress, and the meltwater pressure. In order for crevasses to stabilise, the net stress intensity factor Knet must be equal to the material's fracture toughness Kc. However, these analytical approaches have well-known limitations, such as (i) idealised scenarios and boundary conditions are assumed; (ii) creep effects, resulting from the continual movement of glaciers under their own weight, are neglected; and (iii) crevasse interaction cannot be captured. Recently, computational methods have been used to predict crevasse growth and iceberg calving events. Local and non-local continuum damage mechanics formulations have been presented to predict ice sheet fracture [1–22]. These works have overcome some of the limitations intrinsic to analytical approaches, but often at the cost of using empirical parameters. Variational phase field fracture models offer an alternative approach, enabling the simulation of realistic conditions (3D geometries, multiple interacting crevasses, etc.) and providing a connection to fracture mechanics theory. Phase field fracture models have gained remarkable popularity in recent years due to their ability to predict complex cracking phenomena including crack bifurcation, coalescence and nucleation from arbitrary sites [23–35]. New phase field-based formulations have been presented for dynamic fracture [36-47], ductile damage [48-59], environmentally assisted cracking [30,31], fatigue crack growth [17-33], hydraulic fracture [60-67], and battery degradation [4-37]; among other (see Refs. [68-79] for an overview). In this work, we aim at extending the success of phase field fracture models to the area of glacier crevassing and iceberg calving. To this end, a new phase field formulation is presented capable of capturing the creep behaviour of glacial ice and the role of fluid pressure in driving crevasse growth. Also, for the first time, crevasse interaction is predicted in both 2D and 3D. Very recently, Sun et al. [40-56] used a phase field approach to predict hydrofracture in 2D linear elastic glaciers, assuming compressible behaviour and disregarding creep effects. Unlike them, we base our framework on a stress-based phase field fracture formulation, which offers several advantages in the context of hydrofracturing of glacier crevasses. First, strain energy-based approaches are unsuited for incompressible rheologies. This is not only important due to the incompressible nature of glacial ice, but also because it hinders its integration into large-scale computational models for ice sheet evolution and sea level rise, which assume incompressible flow (see, e.g., the Community Ice Sheet Model (CISM) [57-68]). Second, ice-sheet fracture is driven by tensile stresses and not strains, with crevasses propagating solely in regions where the net longitudinal stress is positive [42]. This is naturally accounted for in a stress-based phase field model, while requiring a particular ad hoc split in strain energy-based formulations [69-79]. Third, a phase field length-scale insensitive driving force can be defined, enabling the use of coarser meshes, a key enabler given the large scales involved. These advantages provide further motivation for this work, presenting the first stress-based phase field computational framework for hydrofracturing of creeping glaciers and ice shelves [1-18]. The rest of the paper is outlined as follows. The theoretical and computational framework presented is described in Section 2. The model is then used in Section 3 to predict hydrofracturing in case studies of particular interest. First, the propagation of single crevasses in grounded ice considering both linear and non-linear rheologies is investigated. A parametric study is conducted to assess the role of relevant material parameters, seawater level and meltwater depth. Second, we simulate the growth of a field of densely spaced crevasses in a grounded glacier, comparing against the predictions of Nye's zero stress model [19-36]. Third, the growth of basal and surface crevasses (and their interaction) is for the first time simulated for a floating ice shelf, using appropriate Robin boundary conditions. Fourth, the combined creep-phase field fracture model is used to predict the nucleation and growth of crevasses in a realistic geometry, corresponding to the Helheim glacier. Finally, we provide the first 3D analysis of crevasse propagation in ice sheets. Concluding remarks end the manuscript in next section [37-54].

2.0 METHODOLOGY

The In this section, we present our computational framework, which encompasses the three elements that are needed to resolve the hydrofracture process taking place in ice sheets; namely, the viscoplastic behaviour of ice, the propagation of meltwater-filled crevasses, and the role of meltwater pressure on crevasse propagation. These are modelled by means of Glen's flow law [24-41], a stress-based phase field description of fracture [1-18], and a meltwater-ice poro-damage model [42-58], respectively. Fig. 2 illustrates upon a single crevasse the mechanistic and modelling assumptions of our framework. In the following, we present the kinematics of the problem (Section 2.1), formulate the energy functionals, particularise the model upon suitable constitutive choices (Section 2.3), and briefly describe the finite element implementation (Section 2.4). Throughout, the formulation refers to a body occupying an arbitrary domain $\Omega \subset \mathrm{R}n$ ($n \in [1, 2, 3]$), with an external boundary $\partial\Omega \subset \mathrm{R}n{-}1$ with outwards unit normal $\mathbf{n}$.

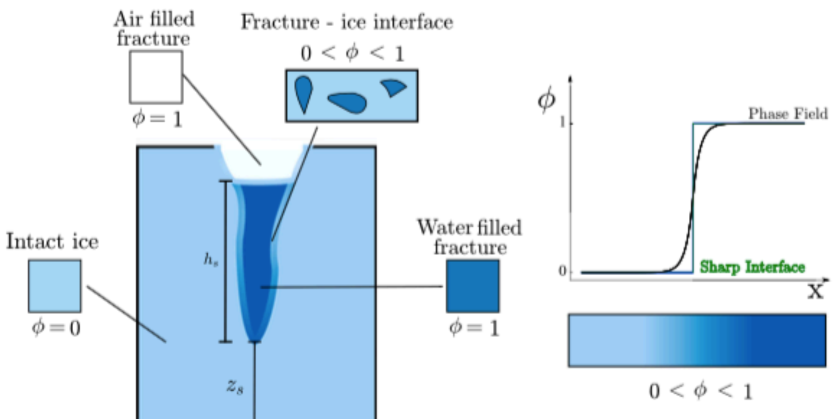

Fig. 2. Schematic diagram of a meltwater filled crevasse in glacial ice, illustrating the intact phase ($\phi = 0$), fully cracked phase ($\phi = 1$) and transition phase ($0 < \phi < 1$). In the damaged and transition phases, there is a hydrostatic pressure contribution to damage arising from the meltwater. Relevant to the poro-damage part of the model, h_s denotes the meltwater depth, and z_s is the distance between the glacier base and the bottom of the crevasse, with z being the vertical height.

3.0 RESULT

In this section, we present a series of 2D and 3D numerical examples, aimed at capturing the propagation of surface and basal crevasses within grounded glaciers and floating ice shelves. For 2D examples, we consider an idealised rectangular glacier of length L = 500 m and height H = 125 m, under the assumption of plane strain conditions. For simplicity, we neglect lateral shear and restrict the domain to a flow line near the terminus with x and z representing the along-flow and vertical coordinates [33-47]. Gravitational load due to self-weight is applied as a uniform body force in the z-direction with a magnitude of $-\rho ig$. We also consider the surface meltwater pressure pw within a crevasse using the poro-damage approach presented in Eq. (19). A Neumann-type traction is applied normal to the ice–ocean interface at the terminus, with the hydrostatic ocean-water pressure varying linearly with depth and a magnitude of $-\rho sg\ \langle \mathrm{h}w - z\rangle$. Boundary conditions that are specific to the grounded glacier and floating ice shelf cases are discussed in Sections 3.1 and 3.3, respectively. Our simulations deal with glacial ice, whose material properties are given in our literature review, along with the densities of seawater and meltwater. The strength σc magnitude is chosen to be an intermediate magnitude within the experimentally reported values of the critical fracture stress in glacial ice, which are in the range 0.08–0.14 MPa [48-71]. An estimate of the phase field length scale, which plays a negligible role in this model, can be obtained through the Hillerborg et al. relation, which for plane strain reads: $\ell = (1 - \nu 2)Kc2/\sigma c2$. Considering the toughness of glacial ice (Kc = 0.1 MPa √m), this gives a magnitude of ℓ = 0.625 m, which is the value adopted here (unless otherwise stated) [58-79]. To attain mesh-independent results, the characteristic element size along the crevasse propagation region is always chosen to be at least 5 times smaller than the phase field length scale ℓ.

Table 1
Material properties assumed in this work (unless otherwise stated). The values are chosen to characterise the behaviour of glacial ice, with the subscript number denoting the relevant reference.

Material parameter	Magnitude
Young's modulus, E [MPa]	
Poisson's ratio, ν [–]	
Density of glacial ice, ρ_i [kg/m^3]	
Density of meltwater, ρ_w [kg/m^3]	
Density of seawater, ρ_s [kg/m^3]	
Fracture toughness, K_c [MPa $\sqrt{m}$]	
Critical fracture stress, σ_c [MPa]	
Creep exponent, n [–]	
Creep coefficient A [MPa^{-n} s^{-1}]	

4.0 CONCLUSIONS

We studied the role of hydrogen in strength degradation of micro-architectured materials. We began by analyzing the Reynold's transport equation for hydrogen diffusion problem and obtained the governing equations for hydrogen concentration under quasi- static loading. We then used the concept of elastoplastic homogenization to bridge the scales and derive the material effective properties. We implemented these theories in a numerical scheme for decoupled diffusion-deformation analysis, in which we update the homogenization algorithm with hydrogen concentration and ow stress through UHARD subroutine and implicit formulae. We applied the model to cubic (withρr = 10 %, 20 % and 30 %) and BCC (withρr = 20 %) unit-cells along with PBC and char- acterized their macroscopic hydrogen degradation laws. Each micro-architectured material has its unique failure loci depending on cell architecture, but one can provide a single expression to describe the behavior of a cubic unit-cell over a range of relative densities. Also, it turned out that the role of trap hydrogen in embrittlement of micro-architecture materials is negligible, especially when the base material has low ductility. For load bearing applications and in presence of hydrogen, the cubic material outperforms the BCC because: (1) at equal hydrogen contents, its maximum strength is higher than BCC, and (2) it undergoes a less sever hydrogen degradation as compared to the BCC. On the other hand, the BCC material has higher ductility which is desirable for certain applications. Generally, micro-architectured materials made of high-strength steels, e.g. AISI 4135, are prone to brittle fracture in the presence of hydrogen. This agrees with what was observed in bulk specimens, e.g. The developed computational scheme is generic and applicable to any periodic micro-architectured material and is an ef cient tool for assessment of hydrogen embrittlement. We proposed the design methodology and numerically characterized the macroscopic hydrogen degradation laws for cubic and BCC unit-cells. The experimental validation of the results on hydrogen embrittlement in architectured materials is suggested as a part of future studies.

REFRENCES

[1] Bitala, Wilmin, et al. "PREDICTIVE ANALYSIS TOWARDS INTEGRATION OF URBAN PLANNING AND GIS TO MANAGE HEALTH CARE ORGANIZATION." International Journal of Science and Advanced Technology 36.17 (2022): 81-87.

[2] Junta, Utian, et al. "PREDICTIVE ANALYSIS OF URBAN PLANNING FOR THROUGH THE OPERATION OF ARTIFICIAL CLOUD NETWORK." International Journal of Science and Advanced Technology 62.42 (2022): 622-627.

[3] Johnima, Akaw, et al. "IMPROVEMENT OF AN SUITABLE MODEL FOR PREDICTING MUNICIPAL SOLID WASTE PRODUCTION." International Journal of Science and Information Technology Research 36.12 (2022): 214-218.

[4] Song, Seong Hyeok, Glaucio H. Paulino, and William G. Buttlar. "A bilinear cohesive zone model tailored for fracture of asphalt concrete considering viscoelastic bulk material." Engineering Fracture Mechanics 73.18 (2006): 2829-2848.

[5] Li, S., et al. "Mixed-mode cohesive-zone models for fracture of an adhesively bonded polymer–matrix composite." Engineering fracture mechanics 73.1 (2006): 64-78.

[6] Sedmak, Aleksandar. "Computational fracture mechanics: An overview from early efforts to recent achievements." Fatigue & Fracture of Engineering Materials & Structures 41.12 (2018): 2438-2474.

[7] Sobhaniaragh, B., S. H. Afzalimir, and C. Ruggieri. "Hydrogen Degradation Effects on Crack Propagation in High-Strength Steels: A Fully Coupled Approach." Fracture, Fatigue and Wear. Springer, Singapore, 2020.

[8] Lotisa, Vivian, et al. "Numerical optimization for esterification of waste coffee grounds oil using reaction external approach." International Journal of Information Systems and Management 64.86 (2022): 891-896.

[9] Inokon, Adisa, et al. "Numerical optimization for esterification of waste coffee grounds oil using reaction external approach." International Journal of Systems Management and Innovation Adoption 124.14 (2022): 891-895.

[10] Lotisa, Vivian, et al. "Assessment of biogas construction potential from sensitive and administered agricultural wastelands." International Journal of Agricultural Management and Development 36.24 (2022): 41-46.

[11] Zerbst, Uwe, Katrin Mädler, and Hartmut Hintze. "Fracture mechanics in railway applications—an overview." Engineering fracture mechanics 72.2 (2005): 163-194.

[12] Kienzler, Reinhold, and George Herrmann. Mechanics in material space: with applications to defect and fracture mechanics. Springer Science & Business Media, 2000.

[13] Pippan, Reinhard, Stefan Wurster, and Daniel Kiener. "Fracture mechanics of micro samples: fundamental considerations." Materials & Design 159 (2018): 252-267.

[14] Pan, Zichao, et al. "A review of lattice type model in fracture mechanics: theory, applications, and perspectives." Engineering Fracture Mechanics 190 (2018): 382-409.

[15] Liu, Shuai, et al. "Surface doping to enhance structural integrity and performance of Li-rich layered oxide." Advanced Energy Materials 8.31 (2018): 1802105.

[16] Xiong, J. J., and R. A. Shenoi. "General aspects on structural integrity." Chinese Journal of Aeronautics 32.1 (2019): 114-132.

[17] Zerbst, Uwe, et al. "Fatigue strength and fracture mechanics–A general perspective." Engineering Fracture Mechanics 198 (2018): 2-23.

[18] Haque, Aziz, and Harvinder Pal Singh. "Does structural integrity following rotator cuff repair affect functional outcomes and pain scores? A meta-analysis." Shoulder & elbow 10.3 (2018): 163-169.

[19] Schultz, Richard A. Geologic fracture mechanics. Cambridge University Press, 2019.

[20] Lynch, Stan. "Discussion of some recent literature on hydrogen-embrittlement mechanisms: addressing common misunderstandings." Corrosion Reviews 37.5 (2019): 377-395.

[21] Djukic, Milos B., et al. "The synergistic action and interplay of hydrogen embrittlement mechanisms in steels and iron: Localized plasticity and decohesion." Engineering Fracture Mechanics 216 (2019): 106528.

[22] Shao, Zhuoping, and Fuli Wang. The fracture mechanics of plant materials. Springer Singapore, Singapore, 2018.

[23] Kundu, Tribikram, ed. Nonlinear ultrasonic and vibro-acoustical techniques for nondestructive evaluation. Springer, 2018.

[24] Dwivedi, Sandeep Kumar, and Manish Vishwakarma. "Hydrogen embrittlement in different materials: A review." International Journal of Hydrogen Energy 43.46 (2018): 21603-21616.

[25] Khatir, Samir, and Magd Abdel Wahab. "Fast simulations for solving fracture mechanics inverse problems using POD-RBF XIGA and Jaya algorithm." Engineering Fracture Mechanics 205 (2019): 285-300.

[26] Bray, Don E., and Roderic K. Stanley. Nondestructive evaluation: A tool in design, manufacturing, and service. CRC press, 2018.

[27] Kurumatani, Mao, Yuto Soma, and Kenjiro Terada. "Simulations of cohesive fracture behavior of reinforced concrete by a fracture-mechanics-based damage model." Engineering Fracture Mechanics 206 (2019): 392-407.

[28] Thöns, Sebastian. "On the value of monitoring information for the structural integrity and risk management." Computer-Aided Civil and Infrastructure Engineering 33.1 (2018): 79-94.

[29] Pro, J. William, and Francois Barthelat. "The fracture mechanics of biological and bioinspired materials." MRS Bulletin 44.1 (2019): 46-52.

[30] Song, Chongmin, Ean Tat Ooi, and Sundararajan Natarajan. "A review of the scaled boundary finite element method for two-dimensional linear elastic fracture mechanics." Engineering Fracture Mechanics 187 (2018): 45-73.

[31] Martin, May L., et al. "Enumeration of the hydrogen-enhanced localized plasticity mechanism for hydrogen embrittlement in structural materials." Acta Materialia 165 (2019): 734-750.

[32] Kitamura, Takayuki, Takashi Sumigawa, and Takahiro Shimada. "Challenge toward nanometer scale fracture mechanics." Engineering Fracture Mechanics 187 (2018): 33-44.

[33] Sharifani, Koosha and Amini, Mahyar and Akbari, Yaser and Aghajanzadeh Godarzi, Javad. "Operating Machine Learning across Natural Language Processing Techniques for Improvement of Fabricated News Model." International Journal of Science and Information System Research 12.9 (2022): 20-44.

[34] Ida, Nathan, and Norbert Meyendorf, eds. Handbook of advanced nondestructive evaluation. Cham, Switzerland: Springer International Publishing, 2019.

[35] de Oliveira, Thaianne S., et al. "2-D fracture mechanics problems by SGFEM." Engineering Analysis with Boundary

Elements 108 (2019): 279-294.

[36] Mohammed, Auwalu I., et al. "Casing structural integrity and failure modes in a range of well types-a review." Journal of natural gas science and engineering 68 (2019): 102898.

[37] Luo, Y., et al. "Linear elastic fracture mechanics characterization of an anisotropic shale." Scientific reports 8.1 (2018): 1-12.

[38] Funari, Marco Francesco, Paolo Lonetti, and Saverio Spadea. "A crack growth strategy based on moving mesh method and fracture mechanics." Theoretical and Applied Fracture Mechanics 102 (2019): 103-115.

[39] Schimleck, Laurence, et al. "Non-destructive evaluation techniques and what they tell us about wood property variation." Forests 10.9 (2019): 728.

[40] Barrera, Olga, et al. "Understanding and mitigating hydrogen embrittlement of steels: a review of experimental, modelling and design progress from atomistic to continuum." Journal of materials science 53.9 (2018): 6251-6290.

[41] Wang, Haijie, et al. "Numerical method for estimating fatigue crack initiation size using elastic–plastic fracture mechanics method." Applied Mathematical Modelling 73 (2019): 365-377.

[42] Nazarchuk, Z. T., and H. M. Nykyforchyn. "Structural and corrosion fracture mechanics as components of the physicochemical mechanics of materials." Materials Science 54.1 (2018): 7-21.

[43] Mandache, Catalin. "Overview of non-destructive evaluation techniques for metal-based additive manufacturing." Materials Science and Technology 35.9 (2019): 1007-1015.

[44] Amini, Mahyar, and Aryati Bakri. "Cloud computing adoption by SMEs in the Malaysia: A multi-perspective framework based on DOI theory and TOE framework." Journal of Information Technology & Information Systems Research (JITISR) 9.2 (2015): 121-135.

[45] Amini, Mahyar. "The factors that influence on adoption of cloud computing for small and medium enterprises." (2014).

[46] Amini, Mahyar, et al. "MAHAMGOSTAR. COM AS A CASE STUDY FOR ADOPTION OF LARAVEL FRAMEWORK AS THE BEST PROGRAMMING TOOLS FOR PHP BASED WEB DEVELOPMENT FOR SMALL AND MEDIUM ENTERPRISES." Journal of Innovation & Knowledge, ISSN (2021): 100-110.

[47] Amini, Mahyar, et al. "Development of an instrument for assessing the impact of environmental context on adoption of cloud computing for small and medium enterprises." Australian Journal of Basic and Applied Sciences (AJBAS) 8.10 (2014): 129-135.

[48] Amini, Mahyar, et al. "The role of top manager behaviours on adoption of cloud computing for small and medium enterprises." Australian Journal of Basic and Applied Sciences (AJBAS) 8.1 (2014): 490-498.

[49] Amini, Mahyar, and Nazli Sadat Safavi. "Critical success factors for ERP implementation." International Journal of Information Technology & Information Systems 5.15 (2013): 1-23.

[50] Amini, Mahyar, et al. "Agricultural development in IRAN base on cloud computing theory." International Journal of Engineering Research & Technology (IJERT) 2.6 (2013): 796-801.

[51] Amini, Mahyar, et al. "Types of cloud computing (public and private) that transform the organization more effectively." International Journal of Engineering Research & Technology (IJERT) 2.5 (2013): 1263-1269.

[52] Amini, Mahyar, and Nazli Sadat Safavi. "Cloud Computing Transform the Way of IT Delivers Services to the Organizations." International Journal of Innovation & Management Science Research 1.61 (2013): 1-5.

[53] Amini, Mahyar, and Nazli Sadat Safavi. "A Dynamic SLA Aware Heuristic Solution For IaaS Cloud Placement Problem Without Migration." International Journal of Computer Science and Information Technologies 6.11 (2014): 25-30.

[54] Amini, Mahyar, and Nazli Sadat Safavi. "A Dynamic SLA Aware Solution For IaaS Cloud Placement Problem Using Simulated Annealing." International Journal of Computer Science and Information Technologies 6.11 (2014): 52-57.

[55] Sadat Safavi, Nazli, et al. "An effective model for evaluating organizational risk and cost in ERP implementation by SME." IOSR Journal of Business and Management (IOSR-JBM) 10.6 (2013): 70-75.

[56] Sadat Safavi, Nazli, Nor Hidayati Zakaria, and Mahyar Amini. "The risk analysis of system selection and business process re-engineering towards the success of enterprise resource planning project for small and medium enterprise." World Applied Sciences Journal (WASJ) 31.9 (2014): 1669-1676.

[57] Sadat Safavi, Nazli, Mahyar Amini, and Seyyed AmirAli Javadinia. "The determinant of adoption of enterprise resource planning for small and medium enterprises in Iran." International Journal of Advanced Research in IT and Engineering (IJARIE) 3.1 (2014): 1-8.

[58] Safavi, Nazli Sadat, et al. "An effective model for evaluating organizational risk and cost in ERP implementation by SME." IOSR Journal of Business and Management (IOSR-JBM) 10.6 (2013): 61-66.

[59] Khoshraftar, Alireza, et al. "Improving The CRM System In Healthcare Organization." International Journal of Computer Engineering & Sciences (IJCES) 1.2 (2011): 28-35.

[60] Abdollahzadegan, A., Che Hussin, A. R., Moshfegh Gohary, M., & Amini, M. (2013). The organizational critical success factors for adopting cloud computing in SMEs. Journal of Information Systems Research and Innovation (JISRI), 4(1), 67-74.

[61] Zalnejad, Kaveh, Seyyed Fazlollah Hossein, and Yousef Alipour. "The Impact of Livable City's Principles on Improving Satisfaction Level of Citizens; Case Study: District 4 of Region 4 of Tehran Municipality." Armanshahr Architecture & Urban Development 12.28 (2019): 171-183.

[62] Zalnezhad, Kaveh, Mahnaz Esteghamati, and Seyed Fazlollah Hoseini. "Examining the Role of Renovation in Reducing Crime and Increasing the Safety of Urban Decline Areas, Case Study: Tehran's 5th District." Armanshahr Architecture & Urban Development 9.16 (2016): 181-192.

[63] Fallahdizcheh, Amirhossein, and Chao Wang. "Profile monitoring based on transfer learning of multiple profiles with incomplete samples." IISE transactions 54.7 (2022): 643-658.

[64] Fallahdizcheh, Amirhossein, and Chao Wang. "Data-level transfer learning for degradation modeling and prognosis." Journal of Quality Technology (2022): 1-23.

[65] Dimitrijevic, Branislav, et al. "Short-Term Segment-Level Crash Risk Prediction Using Advanced Data Modeling with Proactive and Reactive Crash Data." Applied Sciences 12.2 (2022): 856.

[66] Dimitrijevic, Branislav, et al. Segment-Level Crash Risk Analysis for New Jersey Highways Using Advanced Data Modeling. No. CAIT-UTC-NC62. Rutgers University. Center for Advanced Infrastructure and Transportation, 2020.

[67] Sobhaniaragh, Behnam, Seyed Hamidreza Afzalimir, and Claudio Ruggieri. "Towards the prediction of hydrogen–induced crack growth in high–graded strength steels." Thin-Walled Structures 159 (2021): 107245.

[68] Sobhaniaragh, B., S. H. Afzalimir, and C. Ruggieri. "Hydrogen Degradation Effects on Crack Propagation in High-Strength Steels: A Fully Coupled Approach." Fracture, Fatigue and Wear. Springer, Singapore, 2020.

[69] Xiang, Zheng, et al. "Enhanced cyclic fracture mechanics tests to examine morphological and molecular results on slow crack growth in contemporary PE pipe grades." International Journal of Applied Science and Information Science 45.16 (2021): 168-177.

[70] Pan, Bing, et al. "Classifying character focuses for fracture process zone description in mounted carbon or epoxy covers with a convolutional neural system." Australian Journal of Engineering and Applied Science 22.17 (2021): 841-847.

[71] Zhang, Lixuan, et al. "Consequence of the industrialized considerations on the flexible and splintering stuffs of FDM 3D-printed PLA samplings." European Journal of Applied Engineering and Basic Sciences 43.31 (2020): 190-197.

[72] Li, Chang, et al. "Micro Architectures Materials and Hydrogen Embrittlement." International Journal of Engineering and Information Technology 61.39 (2022): 478-485.

[73] Chen, Don, et al. "A stress destruction stage field model on behalf of hydrofracturing of crawling ice shelves and glaciers." International Journal of Computer Science and Engineering Research 86.42 (2022): 1115-1121.

[74] Chen, Lee, et al. "Assessment of current crack width and crack spacing in enormous covered concrete constructions matter to exterior restrictions exploiting RBSM." International Journal of Science and Advanced Technology 12.19 (2022): 12-20.

[75] Yun, Chidi, et al. "Predictive Analytics: A Survey, Trends, Applications, Opportunities' and Challenges for Smart City Planning." International Journal of Computer Science and Information Technology 23.56 (2022): 226-231.

[76] Jackson, Keypi, et al. "Character of Top Leader on Adoption of Cloud Predictive Analysis for Urban Planning of Small and Medium Enterprises." International Journal of Information System and Innovation Adoption 15.11 (2022): 125-133.

[77] Shun, Miki, et al. "Predictive Analysis for Urban Planning based on Cloud Computing Adoption." International Journal of Management System and Applied Science 9.5 (2022): 345-349.

[78] Ewani, Joe, et al. "Smart City and Future of Urban Planning based on Predictive Analysis by Adoption of Information Technology." Journal of Basis Applied Science and Management System 4.8 (2022): 425-431.

[79] Balen, John, et al. "Predictive Analytics Challenges based on Cloud Computing for Urban Planning." International Journal of Information System Management System 23.19 (2022): 744-750.