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Computer-Aided Design AND APPLICATIONS

Application of Computer Aided Design in Intelligent Hardware Design of Logistics Car

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Abstract. In order to solve the problem of AGV running under load, the change of bending strength and deformation leads to the decrease of the carrying capacity and driving stability of the trolley, the author puts forward the application of computer-aided design in the intelligent hardware design of the logistics trolley. Solid modeling and design of the frame are carried out using the three-dimensional modeling software Solidworks, and the structural stiffness, strength analysis and optimization design under bending conditions are carried out based on the finite element analysis software ANSYS Workbench to achieve the lightweight design. The simulation results show that the optimized design meets the requirements, and the weight of the optimized frame is reduced by 14%. Conclusion: This method provides a certain reference for future research and development of AGV.

Keywords: AGV frame; Structural modeling design; Finite element analysis; Strength and rigidity; optimal design
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1 INTRODUCTION

Since entering the 21st century, on the basis of the third industrial revolution, a new round of technological and industrial revolution is setting off a wave around the world. First, in 2013, the concept of "Industry 4.0" was put forward at the industrial exposition in Hanover, Germany, and then in 2015, China issued the "Made in China 2025" national action plan for the development of manufacturing industry as the main body, it means that this new round of industrial revolution is not only a good opportunity for manufacturing to catch up with and surpass the international level, but also an opportunity for the overall industrial transformation and upgrading of the world's manufacturing industry. The maturity of a country's industrial technology often affects its overall productivity level, under the current economic reform trend, developing manufacturing and promoting industrial upgrading are an important factor in accelerating economic growth [1].

At present, the development of domestic manufacturing enterprises in the direction of intelligent production is very uneven, and they lack perfect information intelligent equipment, and are in urgent need of relevant intelligent technology to make changes. Automated Guided Vehicle (AGV) is a classification of intelligent robot equipment. Generally speaking, most of the auto-guided vehicles used in the actual scene are usually controlled by on-board or remote computers, the vehicles are equipped with various sensors for accurate positioning, equipped with safety protection structures to prevent collision with obstacles from damaging the vehicle body, and equipped with navigation control equipment to achieve the vehicle's autonomous movement, a well-designed self-guided vehicle can meet the requirements of safe driving within the route set by the operator in advance, and deliver the materials carried on the vehicle from the starting point to the target point smoothly [2].

Use AGV as a transportation tool for material handling, distribution and recycling in smart factories, it will greatly improve the manufacturing efficiency of the workshop, and can also improve the logistics intelligent management level of manufacturing enterprises, with AGV as the basis of logistics transportation, the intelligent factory can also build a complete set of automatic logistics distribution system. In this context, how to develop an efficient and mature AGV distribution system has gradually become one of the key issues that manufacturing enterprises need to solve to develop intelligent manufacturing plants.

Figure 1 shows the three-dimensional model of AGV frame [3]. The R&D and application of autonomous guided vehicles will inevitably reduce labor costs, improve logistics and transportation efficiency, and greatly bring more profit space for enterprises, at the same time, the difficulties also appear, how to control the cost of developing autonomous guided vehicles is a difficult problem for the manufacturing industry, now the urgent problem to be solved is how to develop autonomous guided vehicle transportation system at low cost to meet the intelligent demand of manufacturing industry, this problem has become one of the focuses in the research field of leading guided vehicles in recent years [4].

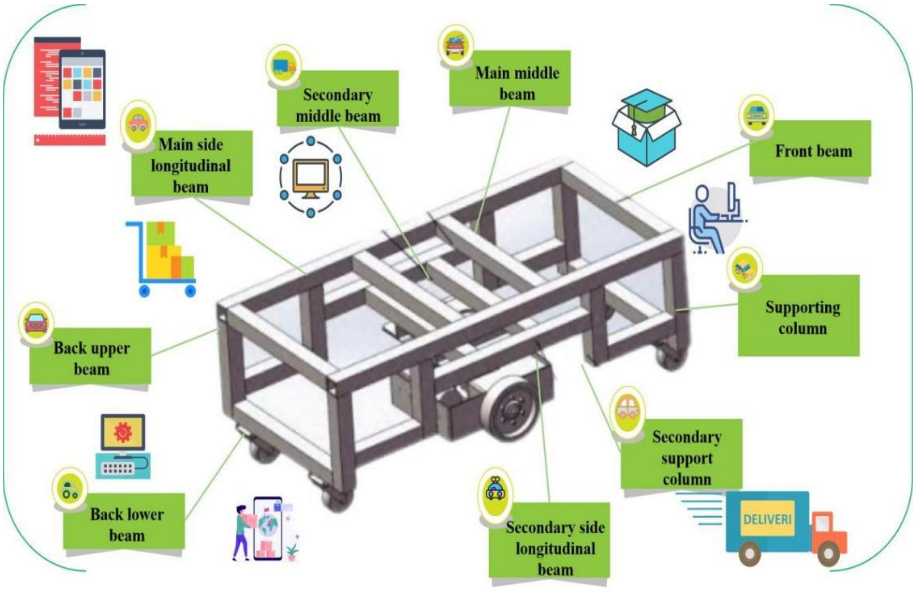

Figure 1: 3D model of AGV frame.

2 LITERATURE REVIEW

In 1953, Barrett Electronics of the United States developed the world's first AGV, which was refitted from a tractor, the control system was composed of vacuum tubes, guided by aerial wires, and used for debris handling in the warehouse, the cost was relatively high. In 1954, the UK developed the first electromagnetic guided AGV, which is more flexible and cheaper than the traction AGV. These advantages have made the AGV widely used in automatic industrial production lines in Europe.

In 1973, the Swedish VOLVO Automobile Company introduced AGV to participate in the assembly work, and it was widely used in the production line, such innovative improvement has greatly liberated human labor and made assembly and transportation more accurate, its application in the automobile field has expanded the application field of AGV. By the 1970s, nearly 5000 AGVs in Europe had been used in logistics warehousing and manufacturing production [5]. At the end of the 1980s, with the development of guidance technology, the guidance technology of AGV developed from a single electromagnetic guidance to a variety of guidance methods, laser guidance, inertial guidance, magnetic stripe guidance, visual guidance and other technologies were gradually applied to AGV technology, which improved the flexibility of AGV and made it easy for AGV to change the guidance path. The emergence of multiple guidance modes has improved the tracking ability of AGV and expanded its application field.

The author mainly studies the design and optimization of a new side beam for the mechanical structure of the frame, and most of the AGVs with light load less than 2t are on the market, and the frame is the main load-bearing carrier of the AGV. The author takes the maximum load capacity of the frame 3t as the design objective, carries out the structural design of the frame, and uses ANSYS finite element analysis.

3 RESEARCH METHODS

3.1 Frame Design Requirements

The AGV frame is equivalent to the automobile chassis and is the key part of the AGV mechanical system. The basic principle of frame design is that the frame layout is simple and convenient for processing. The reasonable design of the frame will be beneficial to the installation of other power systems, control systems and some sensor components without interference; The lightweight design of the frame is conducive to improving the speed and stability of the car movement process, and improving the work efficiency of the car. But the most important thing is that the trolley frame should be able to meet the requirements of load bearing, bending and torsion deformation when the road is flat, static and uneven, so the strength and stiffness of the structure should be designed to meet certain standards.

3.2 Requirements for Frame Model

This time, the AGV frame adopts the double-layer design of side beam type, and the Q235 hollow square tube forms the main structure of the frame. The square tube is made of Q235 hot-rolled or cold-rolled strip steel or coil as the base material, which is formed by cold bending and then welded by high-frequency welding. The upper layer of the side beam can be designed in a variety of ways, either 1~3mm steel plate or aluminum alloy plate can be built on the beam to transport the load, or the upper layer can be modified and riveted to install the lifting steering device and lifting device.

The lower layer supports the main structure and is used to carry the battery mass and other system weights. At the same time, a large number of small holes are left on the square steel so that the reinforcement plate and other control systems can be connected to the frame through bolts. Two drive wheels and four universal wheels are selected for the gear train, and four support wheels are loaded on the four corners of the frame to bear the main load. Two driving wheels are installed in the belly of the car body to bear part of the load, the driving wheels can not only provide driving force for the car movement, but also share part of the load when loaded, thus increasing the load of the whole car.

3.3 Three-dimensional Modeling of Frame

Q235 hollow square tube is adopted for frame beam. Q235 is the most widely used material in engineering, and its elastic modulus E=2.0 × 105MPa, density ρ= 7850kg/m3, Poisson's ratio μ= 0.3. The design structural dimensions of the frame are 1000mm in length, 480mm in width and 290mm in height. The double-deck frame is divided into main and auxiliary frames, the main frame is supported by two main support columns at the front and rear, two main side longitudinal beams and four main cross beams, which play a major bearing role.

The subframe is composed of two auxiliary crossbeams, four lower side longitudinal beams, two auxiliary side longitudinal beams and four auxiliary support columns to fix and strengthen the structure, it is also used to install the gear train, drive device, power device and control system. The beam structural parameters are shown in Table 1 [6].

number	*name*	*Steel selection specification/mm*	*Cross-sectional area/cm2*	*Theoretical quality/(kg·m -1)*	*quantity*	*length/ mm*
1	Main support column	GB/T3094-200040×40×5	6.98	5.48	4	250
2	Main beam	GB/T3094-200040×40×5	6.98	5.48	4	400
3	Main side stringer	GB/T3094-200040×40×4	5.49	4.57	2	1000
4	Auxiliary side stringer	GB/T3094-200040×40×4	5.49	4.57	2	450
5	Auxiliary crossbeam	GB/T3094-200040×40×3.5	4.9	3.85	2	400
6	Auxiliary support column	GB/T3094-200040×40×3.5	4.9	3.85	4	200
7	Lower stringer	GB/T3094-200040×40×3.5	4.9	3.85	4	250

Table 1: Structural parameters of frame beam.

4 RESULT ANALYSIS

4.1 Frame Finite Element Model and Performance Analysis

Finite element analysis is to simulate the real physical system (geometry and load conditions) by using mathematical approximation. With simple and interactive elements, a finite number of unknowns can be used to approximate the real system with infinite unknowns [7-8]. After simplifying the model, replace the complex model problem with the simple model problem and then solve it, the region to be solved is considered to be composed of small interconnected regions of many finite elements, and an appropriate approximate solution is obtained for each small region, and then the total satisfaction conditions of the region to be solved are deduced, the approximate solution of the complex model problem is obtained. There are many commonly used software for finite element analysis, such as ANSYS, which can analyze mechanical, electromagnetic [9], fluid mechanics and other disciplines; Motor finite element analysis software NASTRAN; COMSOL Multiphysics, etc.

The analysis software used by the author is Workbench in the platform of ANSYS for analysis and processing. Workbench is simple to operate and easy to use, it can directly set calculation parameters, such as design dimensions, engineering materials or operating conditions, then submit it to the desired underlying solver for solution. The simulation results are obtained in the analysis module Solution in Workbench [10]. After the overall structural design of the frame is completed, it is necessary to evaluate its bearing capacity more accurately, study its stress distribution, deformation distribution and other data under the maximum load, and judge whether the structural design is reasonable, and optimize the size, so finite element analysis is needed.

The traditional structural analysis and check of strength and stiffness are based on the classical mechanics theory, so there are many problems such as complex calculation, long time consuming and difficult to find the error points if there are errors in the process. However, using the finite element analysis software to analyze the stress and deformation of the AGV frame structure and optimize the size will take less time, reduce the cost of structure use, and quickly complete the analysis task of the AGV frame structure to ensure the scientific, reasonable and reliable design of the AGV body structure.

4.1.1 Frame finite element modeling

When using the 3D software Solidworks to draw the 3D model structure diagram of the frame, in order to reduce the difficulty of mesh division of the finite element analysis, the frame structure model is properly simplified: Ignore the non-bearing components that have little influence on the bending deformation and stress distribution of the frame structure; Ignore the non-connecting holes on the longitudinal and transverse beams [11]; Ignore fillets and small holes with small radius; Ignore the gear train and replace it with fixed constraints to better obtain the finite element mesh quality.

Import the model drawn by Solidworks into the Workbench of the simulation analysis software ANSYS for simulation analysis. The author simplifies some places where stress singularity may occur, such as reserved riveting holes, welds and fillets, the selection of binding contact method and simplified structural model can improve the efficiency of finite element analysis and avoid stress singularity in analysis.

The AGV trolley has bending, turning, starting and stopping working conditions, the author mainly carries out static calculation and analysis of the worst working condition of the AGV under full load - bending working condition, the grid is divided on the finite element analysis software, and the constraint conditions and load are applied to this working condition, the simulation analysis process verifies the rationality of the design. When the frame is fully loaded, the main loads are the weight of the frame, the mass of the load, the mass of the battery and the mass of other systems, some of the other masses are relatively small and can be ignored, which does not affect the analysis results [12].

The dead weight of the frame is applied in the form of gravity, the mass of the goods is applied to the surface of the upper frame on average, and the mass of the battery and other systems are applied to the longitudinal beam of the subframe on average. Considering the influence of uneven road surface, the dynamic load coefficient is taken as 1.2, and the load size of AGV is shown in Table 2 [13-14].

	Dead weight of frame	*Quality of goods*	*Battery pack quality*	*Other system quality*
quality/kg	44	3 000	40	20

Table 2: AGV load Table.

Use Workbench to grid the AGV frame model, the beam grid size in the project is generally 5-10mm, and the average size of the grid set in this project is 8mm. Solid186 unit is used for the frame support column, and Solid187 unit is used for the integral beam, longitudinal beam and the part used for installing the drive device and universal wheel [15-16]. Because Solid186 element has fast calculation speed and short grid generation time, Solid187 element has very strong nonlinear analysis ability.

The whole frame generates 476670 nodes and 20829 units. Check the quality of the mesh after division to avoid solving errors. The mesh quality can be verified by the change of displacement, the mesh accuracy has little influence on the displacement, if the mesh accuracy is changed, the displacement does not change, which proves that the mesh quality is good, secondly, the mesh quality can be explained by comparing the ideal value of the mesh evaluation standard, as shown in Table 3 [17].

Grid evaluation criteria	*Unit quality*	*Aspect ratio*	*Jacobian*	*Warpage factor*	*Parallel deviation*	*Maximum fixed angle/(°)*	*Inclination/ (°)*
Ideal value	1	1	1	0	<15	90	0
Actual average	0.78	2.17	1.1	0	7.9	106.36	0.33

Table 3: Grid quality inspection results.

The overall gravity of the frame is applied through standard earth gravity, and the loaded gravity of the frame is applied to the longitudinal beam and cross beam of the main frame respectively in the form of force, apply the battery gravity and other system gravity to the front and rear longitudinal beams of the subframe respectively in the form of force. The four bottom plates of the subframe crossbeam between the two support columns contact the ground through four universal wheels, so they are constrained at the bottom of the four square plates; Install the drive device and drive wheel between the longitudinal beams at the lower layer of the frame, the drive wheel contacts the ground and supports the frame through the drive device, therefore, a constraint is applied at the simplified driving device; The other beams and slabs are treated by binding contact.

4.2 Analysis of Mechanical Results

ANSYS Workbench is used to analyze the rigidity and strength of the frame, when the car is stationary and moving at a constant speed on a good road surface, all the wheels of the car are in contact with the ground at the same level, and the bending of the frame caused by ground constraints is simulated and analyzed. The grid is processed independently at the maximum equivalent stress, and the structural deformation and stress distribution of the frame are obtained. From the calculation results, it can be clearly found that the stress of most of the frame structures is below 100MPa [18].

As the welded weld of steel structure may lead to stress concentration, therefore, there is obvious stress concentration at the junction of the support column, cross beam and longitudinal beam of the frame, where the maximum equivalent stress reaches 141.95MPa. The stress singularity will occur at the connection of the beam, which can be directly ignored. The stress distribution on the support column is relatively small, and the remaining maximum stress occurs in the middle of the longitudinal beam and the cross beam of the main frame, with the maximum equivalent stress value of 77.122MPa. According to relevant literature, the yield strength of Q235 steel is 235MPa, and the safety factor is 1.5. According to formula (4.1):

$$[\sigma] = \frac{\sigma_s}{S} = 156.7MPa > 141.95MPa \tag{4.1}$$

Where: $[\sigma]$ is the allowable stress; σ_s is the yield strength of steel material; S is the safety factor of steel material [19].

Since the place where stress concentration occurs is not an important part and occurs in the welding part, and the structural analysis of computer software is also affected by many factors, including mesh division, the mesh division may not be perfectly realized in the sharp corner area of the figure, so the stress concentration will exist. However, we try to solve the problem of stress concentration through safety factor, this may push the structural design into an irreversible situation, because it is impossible to design a structure that can bear tension and is theoretically safe enough, therefore, the maximum equivalent stress value generated by stress concentration is ignored, so the strength of the frame meets the requirements.

The maximum deformation of the frame is 0.4587mm in the middle of the two crossbeams of the main frame, and the deformation of other positions is within 0.40mm. Bending stiffness is the change of displacement caused by unit force, so the bending stiffness of the secondary frame is 90000N/mm. According to the design criteria of trucks, less than 2% of the workshop wheelbase meets the design requirements. 1000 × 0.002=2mm indicates that the frame has greater rigidity and has the ability to resist the general deformation of the frame. According to the calculation results, its rigidity design also meets the requirements of frame [20-21].

4.3 Structural Optimization of Frame

From the stress and deformation analysis results, it is known that the maximum equivalent stress mainly occurs at the welding of the support column and the transverse and longitudinal beams, where the stress concentration occurs. However, the maximum stress in other parts is less than half of the allowable stress, which indicates that there is still a lot of surplus for structural design to be optimized.

The optimized structure can bear part of the stress concentration of the support column, significantly improve the support force and reduce the stress concentration, the optimized frame structure is 44kg, the optimized frame mass is 38kg, and the mass is reduced by 14%, it can be seen that the optimized scheme can be implemented, providing a certain basis for structural support for the subsequent lightweight optimization, the parameters and specifications of the optimized hollow square steel pipe are shown in Table 4 and Figure 2 [22].

Number	*Name*	*Steel Selection Specification/Mm*	*Cross-Sectional Area/Cm2*	*Theoretical Quality/(KgM-1)*	*Quantity*	*Length/ Mm*
1	Main support column	GB/T3094-200040×40×4	5.49	4.56	4	250
2	Main beam	GB/T3094-200040×40×3.5	4.9	3.85	4	400
3	Main side stringer	GB/T3094-200040×40×3.5	4.9	3.85	2	1000
4	Auxiliary side stringer	GB/T3094-200040×40×3.5	4.9	3.85	2	450
5	Auxiliary crossbeam	GB/T3094-200040×40×3.5	4.9	3.85	2	400
6	Auxiliary support column	GB/T3094-200040×40×3.5	4.9	3.85	4	200
7	Lower stringer	GB/T3094-200040×40×3.5	4.9	3.85	4	250

Table 4: Structural parameters after optimization.

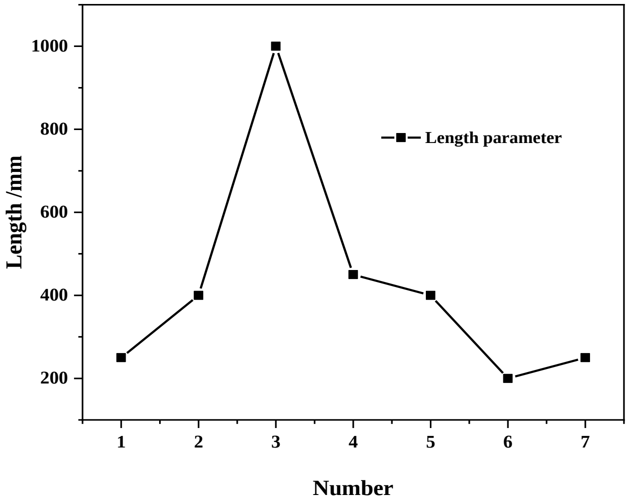

Figure 2: Length parameters of optimized hollow square steel pipe.

The optimized structure is imported into ANSYS Workbench for bending condition analysis. The optimized maximum deformation position and deformation amount have basically not changed, and still occur in the middle of the main beam [23]; The stress concentration still occurs at the junction of the support column, the longitudinal beam and the transverse beam, and the maximum equivalent stress is 149.74MPa; Except for the stress concentration, the maximum equivalent stress appears near the stiffener of the middle support column, and the maximum equivalent stress is 107MPa.

Through the analysis of the optimized results, it can be seen that the stress intensity and deformation under the bending condition after optimization meet the design requirements, and the mass of the frame is greatly reduced, the steel consumption is reduced, which can improve the stability and flexibility of the trolley, therefore, the feasibility of this optimization scheme is confirmed.

5 CONCLUSION

By studying the key points of AGV (automatic guided vehicle) frame structure design, the main and auxiliary frames are designed with double-layer side beam frame, the lower layer is used to install other structures and components, and the upper layer can not only carry heavy objects but also install other devices to achieve multi-function applications. Solid works is used to complete the three-dimensional modeling of the frame structure, and ANSYS Workbench is used to complete the finite element analysis of the frame according to the relevant standards. The simulation results show that the strength and rigidity of the steel structure adopted by the frame meet the design requirements. Through the optimization of the structure, the problem of stress concentration was improved and the weight of the frame was reduced by 14%, the structural performance still meets the strength and stiffness requirements under bending conditions, providing a theoretical basis for future frame design.

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REFERENCES

[1] Schwarz, C.; Wang, Z.: The role of digital twins in connected and automated vehicles, IEEE Intelligent Transportation Systems Magazine, 14(6), 2022, 41-51. https://doi.org/10.1109/MITS.2021.3129524
[2] Sun, Z.; Wang, Q.; Chen, L.; Hu, C.: Unmanned technology-based civil-military intelligent logistics system: from construction to integration, Journal of Beijing Institute of Technology, 31(2), 2022, 140-151. https://doi.org/10.15918/j.jbit1004-0579.2022.010
[3] Li, H.; Lu, L.; Yang, L.: Study on the extension evaluation of smart logistics distribution of fresh agricultural products based on the perspective of customers, Journal of Intelligent & Fuzzy Systems, 43(1), 2022, 615-626. https://doi.org/10.3233/JIFS-212362
[4] Chen, L.; Zhang, Y.; Tian, B.; Ai, Y.; Cao, D.; Wang, F-Y.: Parallel Driving OS: A Ubiquitous Operating System for Autonomous Driving in CPSS, IEEE Transactions on Intelligent Vehicles, 7(4), 2022, 886-895. https://doi.org/10.1109/TIV.2022.3223728
[5] Taylor, G.-D.: Introduction to logistics engineering, CRC Press, 2008. https://doi.org/10.1201/9781420088571
[6] Zhang, X.; Shu, C.; Li, S.; Wu, C.; Liu, Z.: AGVS: a new change detection dataset for airport ground video surveillance, IEEE Transactions on Intelligent Transportation Systems, 23(11), 2022, 20588-20600. https://doi.org/10.1109/TITS.2022.3184978
[7] Díaz, J. L.; García, D. F.; Kim, K.; Lee, C. G.; Bello, L.-L.; López, J.-M.; Mirabella, O.: Stochastic analysis of periodic real-time systems, In 23rd IEEE Real-Time Systems Symposium, 2002, 289-300. https://doi.org/10.1109/REAL.2002.1181583
[8] Zhang, H.; Li, Z.; Zheng, S.; Liu, Y.; Zheng, P.; Zou, X.: Leader-Follower cooperative localization based on VIO/UWB loose coupling for AGV group, The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 46, 2022, 263-269. https://doi.org/10.5194/isprs-archives-XLVI-3-W1-2022-263-2022
[9] Pana, V.-S.; Babalola, O.-P.; Balyan, V.: 5G radio access networks: A survey, Array, 14, 2022, 100170. https://doi.org/10.1016/j.array.2022.100170
[10] Zhu, W.; Zhou, Y.; Huang, J.; Guo, S.: AGV Positioning Based on Multi-sensor Data Fusion, Science, 7(6), 2022, 118-123. https://doi.org/10.11648/j.mcs.20220706.13
[11] Tanabata, T.; Kodama, K.; Hashiguchi, T.; Inomata, D.; Tanaka, H.; Isobe, S.: Development of a plant conveyance system using an AGV and a self-designed plant-handling device: A case study of DIY plant phenotyping, Breeding Science, 72(1), 2022, 85-95. https://doi.org/10.1270/jsbbs.21070
[12] Cheng, H.; Sun, Q.; Li, L.; Zou, Y.; Wang, Y.; Cai, T.; Ming, J.: Emerging era of electrolyte solvation structure and interfacial model in batteries, ACS Energy Letters, 7(1), 2022, 490-513. https://doi.org/10.1021/acsenergylett.1c02425
[13] Chen, L.; Whyte, J.: Understanding design change propagation in complex engineering systems using a digital twin and design structure matrix, Engineering, Construction and Architectural Management, 29(8), 2022, 2950-2975. https://doi.org/10.1108/ECAM-08-2020-0615
[14] Popli, R.; Kansal, I.; Verma, J.; Khullar, V.; Kumar, R.; Sharma, A.: Road: robotics-assisted onsite data collection and deep learning enabled robotic vision system for identification of cracks on diverse surfaces, Sustainability, 15(12), 2023, 9314. https://doi.org/10.3390/su15129314
[15] Barath Kumar, M.-D.; Manikandan, M.: Assessment of process, parameters, residual stress mitigation, post treatments and finite element analysis simulations of wire arc additive

manufacturing technique, Metals and Materials International, 28(1), 2022, 54-111. https://doi.org/10.1007/s12540-021-01015-5
[16] Sadique, M.-R.; Zaid, M.; Alam, M.-M.: Rock tunnel performance under blast loading through finite element analysis, Geotechnical and Geological Engineering, 40(1), 2022, 35-56. https://doi.org/10.1007/s10706-021-01879-9
[17] Van Vinh, P.: Finite element analysis of functionally graded sandwich plates with porosity via a new hyperbolic shear deformation theory, Defence Technology, 18(3), 2022, 490-508. https://doi.org/10.1016/j.dt.2021.03.006
[18] Hossain, R.; Azad, A.-K.; Hasan, M.-J.; Rahman, M.-M.: Radiation effect on unsteady MHD mixed convection of kerosene oil-based CNT nanofluid using finite element analysis, Alexandria Engineering Journal, 61(11), 2022, 8525-8543. https://doi.org/10.1016/j.aej.2022.02.005
[19] Rajad, O.; Mounir, H.; Marjani, A.-E.; Fertahi, S. E.-D.: Nonlinear modeling analysis of the coupled mechanical strength and stiffness enhancement of composite materials of a Horizontal Axis Wind Turbine Blade (HAWTB), International Journal on Interactive Design and Manufacturing, 16(2), 2022, 469-492. https://doi.org/10.1007/s12008-021-00790-0
[20] Ascione, F.; Granata, L.; Lombardi, A.: The influence of the hygrothermal aging on the strength and stiffness of adhesives used for civil engineering applications with pultruded profiles: an experimental and numerical investigation, The Journal of Adhesion, 98(12), 2022, 1733-1771. https://doi.org/10.1080/00218464.2021.1936507
[21] Dolatshahi, K.-M.; Beyer, K.: Stiffness and strength estimation of damaged unreinforced masonry walls using crack pattern, Journal of Earthquake Engineering, 26(2), 2022, 837-856. https://doi.org/10.1080/13632469.2019.1693446
[22] Nair, P.-S.; Nair, S.; Sarkar, S.; Arockia Doss, A.-S.; Dinakaran, D.: Design and Analysis of ASRS Using AGV for Rapid Inventory Storage System, Trends in Manufacturing and Engineering Management: Select Proceedings of ICMechD 2019, 2021, 861-872. https://doi.org/10.1007/978-981-15-4745-4_75
[23] Chen, Z.-P.; Feng, D.-C.; Cao, X.-Y.; Ma, K.-J.; Zhu, S.; Wu, G.: Probabilistic seismic demand and fragility analysis of a novel mid-rise large-span cassette structure, Bulletin of Earthquake Engineering, 2022, 2022, 1-31. https://doi.org/10.1007/s10518-021-01222-w