Damage Analysis Using Artificial Intelligence Techniques on Composite Materials

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Introduction

Depending on technological progress, the definition of Artificial Intelligence (AI) varies. AI can be expressed as enabling a computer or robot to do human-specific tasks. This term is used for the development of systems that humans are able to process such as reasoning, meaningful action, situation tracking, or learning from past experiences (Copeland, 2022). By using data, AI facilitates our work by conducting the general tasks that humans generally do. Therefore, artificial intelligence; The voice assistant can offer higher quality, more precise, and faster solutions in translations, consultancy suggestions, location finding, social and cyber security, health services, e-commerce, robot assistant, defense industry, and industrial applications. The means of accessing information are everywhere in our lives. "Data" constitutes the most essential part of the training of artificial intelligence. The efficiency of AI increases as the size, volume, and functionality of data increases. Today, data production has reached incredible dimensions, and the available data and the technological infrastructure required for processing data are also very advanced; Accordingly, AI solutions have reached high efficiency. However, the inadequacy of traditional data processing techniques brings "Big Data" and its solutions. Data volume, speed, and data diversity constitute the main components of "Big Data" which enables us to conclude the processes that would be impossible or inefficient without it, faster and more efficiently. The main areas of use of AI can be listed as follows. Image Processing, Voice Processing, Text Processing, Data Processing, Health Data Analysis, and Treatment Planning, Unmanned – AI Assisted Driving (autonomous) Systems, Insurance and Finance, Big Data Analytics, Smart Applications in Agriculture and Livestock, Cyber Security, Industrial applications, Like Damage Analysis. Like every developed technology, AI applications can be used for different malicious purposes. AI; The use of personal and security data during training may cause different problems if the data is collected illegally. No technological development is scary, provided that ethical, moral, and confidentiality rules are adhered to.

'Data' constitutes a foundation for AI and machine learning (ML). It is the value of qualitative or quantitative variables about persons or objects. Algorithm; It is the process of problem-solving or reaching a result more quickly and effectively by applying well-defined rules and procedures step by step. ML is a branch of data analysis methods that automatically creates an analytical model. It is a sub-field of AI and the idea that systems can be trained by data and take decisions while requiring minimum human intervention constitutes its base. Deep learning is classified among machine learning methods that are developed for computers to perform higher cognitive actions. It is the use of neural networks consisting of many artificial neural layers. Deep learning is the most important element behind image-based AI applications, especially autonomous vehicles (Ballard & Brown, 1982; Sonka et al., 2008; Vandoni, 1996). In Cognitive Science, the processes of the human brain such as information processing and decision making are being studied. Inventions in Cognitive Science are very essential for the computer to think like a human as the main focuses in this field are decision making, processing of information, etc. AI application is generally maintained in the open source ecosystem. Therefore, there are many programming languages, libraries, and application environments. These languages are; Python, C++, Java, C sharp, etc. Libraries are TensorFlow, PyTorch, Knet, Apache Spark, OpenCV, H2O, etc. The types of equipment used are; CPU, GPU, FPGA, ASIC, and TPU. No matter how AI applications evolve, the majority of professions will need human participation. Consequently, the expectation of different new business areas created with AI will emerge is very logical. In addition, AI provides reliable solutions at critical points such as malware analysis or detection in cyber security. AI applications are created especially for the field. These applications are used as decision-making aids, not decision-makers.

AI Techniques

Today, the drawbacks of the rapidly developing technology on people resulting from industry breakthroughs and its negative effects on humanity have been reduced. The developments that are aimed for the protection of the comfort and health of humanity together with inventions and discoveries resulting from industrial breakthroughs should not be ignored. Researchers have tried to design an automatic human model that works with the least error to achieve maximum efficiency at every stage of production. AI has sub-branches such as problem-solving, fuzzy logic, robotics, expert systems, and artificial neural networks (ANNs), and each sub-branch studies one of the human behavior and thinking methods as a principle (Di Scalea et al., 1999).

Machine Learning

Machine learning (ML) algorithms are advantageous tools for structural state monitoring because they can automatically weed out patterns in datasets after they are properly trained. Especially, ANNs are used to handle damage identification problems that can be differentiated into "healthy" or "damaged", which are typical examples of binary learning. A neural network capable of applying dual learning can be modeled by following two approaches: Discrimination-based learning and Recognition-based learning. The first method is about training the network using both 'positive' and 'negative' samples and enabling it to differentiate between the two; meantime in the later, training is done using only 'positive' samples and can only recognize them (Japkowicz, 1999).

Deep Learning

After its success in ImageNet, a large-scale visual recognition competition held for object classification, in 2012, Deep Learning (DL) became widely noticeable. The primary reason why DL is prominent is that there is an adequate level of data for training, and secondly, there is a hardware infrastructure to process this data. The algorithms that train DL models used in the complicated tasks today are similar to the learning algorithms used to solve toy problems in the 1980s but have made changes to the models prepared with these algorithms that simplify the training of very deep architectures. In addition, another important development today is to provide these algorithms with the necessary resources required to be efficient. Data, which is the first of these resources, is provided by the increasing digitalization of society. With the increase in activities performed on computers, more transactions are recorded. As computers become more networked, it has become easier to centralize these records and turn them into a dataset suitable for machine learning applications. Deep learning, image and sound analysis, robotics, autonomous vehicles, gene analysis, disease diagnostics, virtual reality, etc. have been used in various fields. The biggest reason for this degree of prevalence is the high accuracy achieved in solving problems. Indeed, some problems such as sound and image processing have exceeded the human level. Deep learning was used to colorize images and pictures taken without color. In a silent video, based on the prediction of speech by imitating the lip movement of people, the silent video was voiced with deep learning. While the success of people who guessed by reading the lip movement was 52%, the success rate in this study conducted with deep learning was 93%. Obtaining a picture in a sketch, the shape of an object from a drawing, or a real map from a map sketch has become possible with deep learning. Recording of images used by large corporations such as Facebook and Google, object identification, and classification of images were carried out with deep learning models. In the study, the movements in the human skeletal structure were modeled in two dimensions and the conversion of normal writing to handwriting was carried out with deep learning. It has been used with a deep learning structure to voice a text that people have never spoken by synthesizing their old speeches in a way to read it live. These studies have also been extensively used in voice identification, natural language processing, and robotic applications (Inik & Ulker, 2017).

Fuzzy Logic

Experimental studies are very important for designers in solving engineering problems in industrial applications. These studies involve many disadvantages such as time and cost requirement and non-standard environmental conditions. Thus, with the developments in computer technology, various analysis programs that have become widespread and accepted industrially or computer software developed for very specific problems to be examined are used. Fuzzy expert systems, one of them, make reasoning by using numerical operations instead of symbolic reasoning, unlike traditional expert systems (Zadeh, 1983). With its use in expert systems, efficiency increases and turnaround time decreases (Zimmermann, 1996). Statistical methods in damage analysis is also another field where it can be applied. However, studies have shown that the fuzzy expert system delivers better results. It is concluded that computer-aided analysis studies save time and waste no material. (Balli & Sen, 2014).

Fuzzy expert systems are used in linear and non-linear control, sample recognition, financial systems, business research and data analysis, etc. Many systems can be modeled and copied with the help of fuzzy systems. Today, it is seen that fuzzy logic has become quite widespread with projects and research around the world. Some of these are fuzzy logic control systems for mining in deep seas, sample identification using fuzzy logic and genetic algorithm, zooming criteria for fuzzy modeling, sample identification in medical imaging, event detection based on fuzzy logic for intelligent path control. Fuzzy logic is emerging as a useful tool for home management-specific entertainment electronics, diagnostic systems, and other expert systems, as well as for the control of dark zone systems and complex industrial processes. Fuzzy has become a keyword for marketing. Electronically created articles that do not have a fuzzy component are gradually excluded. Fuzzy logic research in Japan is supported by a huge budget. In Europe and the USA, many efforts are being made to capture the extraordinary achievements of the Japanese. For example, NASA space agency is trying to apply fuzzy logic for complex docking maneuvers (Forsyth & Ponce, 2003). Your fuzzy logic;

- Being close to one's way of thinking,
- His practice does not need a mathematical model,
- Its algorithm is simple, so it costs cheap, its advantages,
- Dependence of the expert on the creation of the rules in practice,
- It may take a longer time because the membership functions are found by trial and error method,
- The difficulty of performing the stability analysis is; are the disadvantages

Artificial Neural Networks

They are information processing systems inspired by the way how human brain works and the Artificial Neural Network (ANN) established by the combination of artificial nerves. ANN consists of artificial nerve cells interconnected in various ways and is usually arranged in layers. It can be produced with electronic circuits as hardware or as software on computers. Each neuron in this network has main parameters, namely input (dendrite), output (axon), connections (snaps), and cell nucleus.

We can list some applications of ANN in the industry:

- Production: Automation of robot and control systems, production and quality control, part selection in assembly.
- Medicine: Voice analysis for the hearing impaired, diagnosis and treatment of symptom diseases, surgical imaging, analysis of side effects of drugs, reading x-rays
- Military: Processing radar signals, developing new and advanced weapons, reconnaissance, optimizing resource use, target identification, and tracking.

Extraction of ANN Models:

- The network structure
- To feed forward and backward
- Whether the weight matrices are symmetrical or asymmetric and their values are constant or variable,
- The node characteristics in the network,
- Whether the threshold function used is analytic or stochastic,
- To the node, only analog / secondary or continuous values can be applied,
- Education or learning rules; it depends.

Artificial neural networks have many uses. Some of these are classification, clustering, prediction, pattern recognition, function approach, and optimization. Artificial neural networks are a powerful technique because of their non-linearity, ability to learn and generalize, adaptability, low error tolerance, and speed. In particular, the low tolerance for errors and the rapid resolution of problems. makes artificial neural networks one step ahead of other algorithms.

AI solutions are a set of algorithms applicable to perception and cognition that involve training by the data and experiences that mimic human intelligence and abilities. Convolutional neural networks (CNNs) are deep ANNs mainly used to classify and cluster images and perform object recognition. These algorithms can detect human faces, people, street signs, tumors, platypuses, and process many other aspects of visual data. Keeping that in mind, as a reference to detect damage areas of a car and classify the damage level, CNNs can be used. It uses object detection and classification models such as no damage, light damage and heavy damage together to measure the damaged area and level by processing images. Hence, it can be used successfully in vehicle damage analysis for the insurance market. (Di Scalea et al., 1999).

Genetic Algorithm

A Genetic Algorithm (GA) is a search model modeled on the mechanism of change in nature. The method is used to separate specific data from the general data set. In the early 1970s, Holland introduced GA. Genetic algorithms are a probabilistic search method.

- Optimization: It is used in genetic algorithms, circuit design with numerical optimization problems, solution of nonlinear equation systems, and factory/production planning.
- In machine learning: Genetic algorithm is used in robot sensors, neural networks, chip design, and protein structural analysis.
- It is used in elevator control systems.

Expert Systems

It has contributed to the science of management and expanded its boundaries by enabling the analysis of unstructured problems. Expert systems can only be used by an expert.

A solution can be reached that can not be solved by a human. They are computer programs that are equipped with a piece of particular knowledge and that can provide solutions to field problems as any expert can find. The reason why the term expert system is used here is that the system tends to take the place of one or more experts by knowing. The aim here is to develop an expert system like or better than an expert person. Although obtaining such a system does not necessarily mean one becomes an expert, but enables them to complete a part of or all of the work of an expert through the system. In general, such as product design, process planning, medical treatment, quality control, sound detection, image recognition, robotic applications, design probability, signal analysis, configuration training, aerospace engineering, medicine, agriculture and other engineering designs, computer-aided design systems. It provides the data flow for routine work, keeps it under record, and allows it to be controlled.

Advantages and disadvantages:

- Explaining how and why a conclusion is drawn

- Third parties can easily change expert systems by producing new rules.
- Finding an expert who can give the information to the expert system may not be easy.
- Experts may not state their knowledge in rules.

Usage areas:

It is used extensively in areas such as product design, production planning, medical, treatment, quality control records, sound processing, image recognition, robotic applications, error correction, and educational software (Zimmermann, 1996).

Ant Algorithms

The ant colony optimization algorithm is created to obtain the closest optimal solution for optimization problems involving combination calculations. The areas where these algorithms are applied:

- Robotic applications
- Sales-marketing Problems
- Traffic management
- Telecommunications

Image Processing

Today, the applications of AI methods in engineering disciplines are becoming highly popular, bringing solutions to engineering limitations and creating alternative methods and techniques to the ones that are used today. The image processing technology is one of the AI methods. Image processing includes many processes such as obtaining, digitizing, and improving the image. Civil engineering is also one of the fields in that Image Processing technology is utilized widely. There exist various studies, especially on concrete technology and material science. An analytical model is created on the digitized image by combining image processing and ANN. Using image processing and ANN together gave more meaningful results in measuring the compressive strength of concrete compared to other non-destructive methods. Therefore, the image processing mechanism can be regarded as an alternative analysis method (Cankaya et al., 2013).

The ability of a computer to extract meaning from images is referred to as Computer Vision. Security, defense, health, and industrial production are some of the areas in which this method has been applied. This is an interdisciplinary field dealing with making sense of digital images or videos. With engineering methods, serves to process and continuously run the tasks that the human action system can do. Computer vision tasks involve taking, processing, and analyzing digital images to produce digital information. (Klette, 2014; Morris, 2004; Shapiro & Stockman, 2001).

The scientific discipline of computer vision is concerned with the scientific knowledge behind artificial systems that extract meaningful information from images. Image data; videos can be in many forms, such as images from multiple cameras, multidimensional data from a 3D scanner, or images from an industrial image scanning device. It is necessary to integrate the technological disciplines, theories, and models of computer vision into computer vision systems. The fields of object detection, event detection, video surveillance, object recognition, learning, motion prediction, automatic image creation, and image repair can be listed under the Computer Vision field.

AI Applications in the Industry

- Electronic control systems, decision making, process planning (Fuzzy logic)
- Composite cable laying, circuit design: (Genetic algorithm)
- Optimization: It is used in genetic algorithms, circuit design with numerical optimization problems, solution of nonlinear equation systems, and factory/production planning.
- Transportation automation: For example, precise logic and expert systems can be used in autonomous vehicle driving techniques and signaling.
- In the repair and design of complex electronic and electromechanical systems.
- Design and fault finding of computer and communication systems.
- Many applications related to space (expert systems)
- Search Engines (Yahoo, Google…) (expert systems)
- Routine day trading robots (expert systems)
- Applications in the fields of telecommunications, image and information comparison, automatic information services, multiple translations, consumer payment systems
- Electronics: Code sequence prediction, assembly and repair of chip circuits, voice synthesis, non-linear modeling
- Industry: Process control in industry, product design, and analysis, method and machine learning, part identification, surface quality inspection systems, quality control in welding production, paper quality control, computer chip quality control, grinding methods analysis control, chemical product design analysis, machine maintenance analysis, cost planning and management

- Estimation of gas volume produced by furnaces in an industrial process
- Ability to work with the voice on mobile phones
- It is applied greatly in the areas such as online carbon flow measurement and waste gas management for coal power stations.

Sensors Used in Industry Applications of AI Technology

Sensors give automatic devices the ability to investigate and analyze events around them through sight, touch, and other senses, and as a result act more intelligently. Image sensors (Vision Sensors) are used for part recognition and part measurement. Some sensors measure temperature, power, and shape.

Sensors serve for controlling, protecting, and inspecting industrial processes. They are tools that convert measured physical properties, quantities, and conditions into usable electrical data. There are mechanical, thermal, electrical, magnetic, radiation, and chemical sensor versions (Bozuyuk et al., 2005).

Damage Assessment Applications in Composite Materials

Damage is a term to define a phenomenon that harms normal functioning and changes material performance. Machine learning-based structural condition investigation in composite materials requires the identification of different damage-related indicators based on the data and its unique properties. Damage diagnosis is a well-known engineering problem. Eliminating critical aspects of damage is essential for the efficiency of the ML method. However, machine learning tools are critical for such damage to any structural system (e.g. aerospace, petrochemical, etc.). As composite materials became very popular in certain sectors, the need for early error assessment has arisen by using artificial neural networks. Composite materials have various types of complex damage due to their heterogeneous nature such as interlayer porosity, delamination, fiber disorientation, matrix cracking, and crushing and voids (Smith, 2009). The visual methods can neither detect the onset nor the development process of damage in composite structures due to the complexity issues. Early detection of faults is what most studies aim for. Considering this, the expectation that the usage of AI techniques will be a very important method for damage assessment is very rational (Patro et al., 2021).

In damage detection mechanisms, the method requires measuring every change in structure that is intended to be used to build, train, and test ANNs. After the training phase, the interrelationships between the changes that represent the ‘fingerprint’ of the studied structure are analyzed by networks. The differences in the distribution of these changes are captured by evaluating the differences in the variance correlations previously defined. Any damage situation that changes this distribution is considered an important reason for this further investigation (Califano et al., 2020). Convolutional neural networks are also successful in civil engineering applications and fatigue analysis of aircraft structures (Oh et al., 2019).

Fiber Reinforced Composites

Today, the usage of polymer composites as engineering materials became a general trend. Designing the properties of polymer composites is its most important advantage. It can be designed by choosing the right compound and the correct manufacturing process to meet a specific goal of engineering practice. Some basic parameters in the production process, eg. The curing temperatures and production rate that govern the final quality of the composites must also be analyzed. Modeling the relationships between fatigue, wear, combined loading, and creep) often involves the creation of a mathematical tool from experimental data; once established, it can substantially lower the experimental burden in the designing process of new polymer composites (El Kadi, 2006).

Composite materials have enormous applications in various fields. Thus, obtaining an efficient damage detection method to prevent permanent damage is highly crucial. It is critical to consider all damage types as there exist multiple damage modes and the data is available in different formats. Deep neural networks are capable of solving similarly complex problems. The specific objectives developed for this are 1) to assess the performance of image coding algorithms, 2) to classify damage using data from individual samples, and 3) to classify damage using mixed data from multiple samples. Efficient structural health monitoring (SHM) strategies must be employed to reduce maintenance costs and prevent the permanent failure of composite structures. This method is a heated topic that has been greatly researched in recent years. Structural health imaging methods use data transmitted by a network of sensors attached to the structure to determine the damage status (H. Liu et al., 2017; Molchanov et al., 2016). Fekrimandi et al. (2016), proposed a methodology based on multilayer perceptron and radial-based functional neural network parsers to detect ultrasonic waves in plates as the charge on composite plates. Unlike traditional methods, deep learning algorithms such as Convolutional Neural Networks (CNN) do not require manual material feature extraction and are widely used in classification problems involving signals that are difficult to detect (Zhao et al., 2016). In composites, the damaged area consists of matrix cracks and interlayer delaminations. Considering the overall damage area for analysis, delamination plays the most important role in damaging composites. Because composite materials have different failure modes, such as fiber cracking and delamination, it is important to consider multiple damage detection or measurement techniques. Thus, more efficient damage detection performance can be achieved by combining these measurements using data fusion and a convolutional neural network. Therefore, data aggregation techniques, when combined with a deep neural network, can resolve the complexity of damage classification in composite materials with multiple damage modes. (Dabetwar et al., 2020).

The artificial neural network has recently been used in the fabrication processes of fiber-reinforced composites and in observing and modeling their mechanical behavior. A recent study by Zhang and Friedrich (2003) observed the applicability of neural networks to polymeric composites, polymers, metals, and other materials. Hajela (Hajela, 2002); In his study, he discussed the applications of ANNs towards the mechanical properties of fiber-reinforced polymeric composite materials in the multidisciplinary field of aviation. In experiments on pultruded glass-epoxy composites, material temperature is the input of the neural network. The results were similar for the load-longitudinal strain and load-transverse strain curves for the glass-fiber composite. The temperature compensation is independent of the structure material under test and depends only on the thermal properties of the strain gauge. Lee et al. (1999), performed biaxial tests on cross-ply composite tubes made of T300 carbon/epoxy. Damages were estimated using Tsai-Wu and optimized tensor polynomial theories. Comparing the results with the findings of Artificial Neural Network, it became clear that ANN had the smallest error rate of the three methods used., Stone and Krishnamurthy (1996) presented a neural network thrust controller to minimize this problem. Delamination monitoring of composite laminates with the help of ANNs was also investigated by Todoroki (Todoroki, 2001). The detection of cracks or defects in composite materials is extremely important considering the recent growth in the applications of composites in various engineering operations. Although conventional ultrasonic techniques are used for this, damage detection has been challenging as the measured signals, the inhomogeneity of the material, or the reflection of many waves from different laminate interfaces in the composite plate. Some studies analyze this issue. For example, Al-Assaf and Al-Kadi (Al-Assaf & Al-Kadi, 2001; Al-Kadi & Al-Assaf, 2002) investigated fatigue life prediction of fiberglass/epoxy laminate using neural networks. In the first study (Al-Assaf & El Kadi, 2001), the usefulness of using neural networks to predict fatigue damage was investigated and they concluded that its use is appropriate. The damage analysis for carbon/epoxy nano-reinforced composites was done using the artificial neural networks method. It is concluded that ANNs are a high assumption method. From these examples, it is understood that various methods are used in the damage estimation of composite materials (Lee et al., 1999).

Applications in Medicine

In the systems of medical diagnosis, satellite image analysis, license plate, and face recognition, the detail is very crucial. The spread of deep learning and the introduction of convolutional neural networks necessitated super-resolution. Thus, super-resolution methods with deep learning based became very popular in the literature. (Shapiro & Stockman, 2001).

Buckling Load Analysis

Numerical analysis methods such as boundary elements and finite differences are used effectively today. With the achievements in computer technology, different analysis techniques had emerged. For example, AI application is utilized in industry, medicine computer, economy and military fields, and structural engineering. Axially loaded columns are designed considering the buckling loads they can carry. A multi-layered mesh structure is constructed that gives the buckling load of the axially loaded columns for various support conditions. A back propagation training algorithm was used and the results are of high sensitivity (Zhang & Friedrich, 2003).

AI in Creep-Fatigue Loads

ML framework can be utilized to examine the probabilistic damage distribution under the creep-fatigue interaction. This type of probabilistic damage assessment has significant potential in creep-fatigue life design for material safety (El Kadi & Al-Assaf, 2002). The main factors that alter the mechanical properties of materials and structures are Long-term complex load and extremely high temperature (Dasgupta et al., 1992). In such a case, creep and fatigue damage accumulates gradually, and the material is damaged when the allowable damage exceeds its critical value. (Robinson, 1952). As a result, the accumulated creep and fatigue damage to fracture for the material also indicates scattering. (D. Liu et al., 2016).

Acoustic Emission Technique

The acoustic emission (AE) technique has become a well-known method for monitoring structural health. The detection and analysis of elastic Acoustic emission waves, including piezoelectric plate active sensors (PWAS) and time and frequency analysis, are effective in obtaining information about fatigue cracking. However, (i) the relationship between fatigue crack length and Acoustic emission signal traces and (ii) AI (AI) methodologies detecting Acoustic emission wave analysis are remains topics that require mentioning. To figure out the effects of acoustic emission waveforms on fatigue crack length, a finite element model (FEM) and convolutional neural network and acoustic emission signals are used together in the same crack. Hence, it was possible to predict the acoustic emission signals match the finite element simulations with a high accuracy level is a possibility. AI is a highly efficient way to predict fatigue crack length considering the accuracy level.

Safety and reliability are extremely important for engineering structures still in service. There are possible failure mechanisms in all environmental and mechanical conditions that engineering structures are exposed to. Metal fatigue includes fatigue, static failure, and friction damage based on mechanical loading and environmental conditions. As structures subject to fatigue continue to increase in current and future engineering applications, a robust and efficient method to monitor their structural integrity of any kind during use is needed (Garrett et al., 2022). The field of structural health monitoring (SHM) is a rising methodology for detecting modes of damage, such as fatigue damage, in these structures (Catbas et al., 2008; Su et al., 2006). The general concept is that when energy is released from a fatigue crack, it resonates with the crack, forming a standing wave pattern. The wave model contains frequency information about the resonant frequencies of the crack. Using this understanding, and AI signal analysis system is proposed that can distinguish the acoustic emission wave information and predict the length of the crack from which it originates. This system will provide significant advantages in terms of periodic maintenance in various industries and engineering structures. AI competencies have been similarly researched and used in recent years. Tang et al. (Kabaldin et al., 2020) and Xu et al. (Xu et al., 2020) used machine learning clustering techniques to detect fracture modes in fatigue-loaded wind turbine blades, respectively. In the active control of structural systems, there are studies on the application of neural networks for the acoustic emission properties of composite smart structures Lee (Lee et al., 1999).

In polymer composites, enabling the network to solve material problems requires experimental data in large amounts. However, when this process is finalized, when the network is able to solve material problems, the need for more experiments for the network disappears, a new and smaller data with similar effects can be predicted.

AI in Impact Loads

The impact has one of the most dangerous effects on fiber-reinforced composites. Chandrashekhara et al. 1998, by training ANN with the findings of the finite element analysis, analyzed the impact reaction of the composite plate. In the study, finite element analysis and a neural network is used to calculate the strain state and contact force for the low-velocity impact (El Kadi, 2006). Recently, ANNs became a mainstream method to model the mechanical behavior of fiber-reinforced composite materials. Designing structures and components using recently developed composite materials often requires extensive (and expensive) test programs.. Ideally, using a small dataset of the test results, the designer can accurately measure the performance of the new, or existing material under untested conditions. (El Kadi, 2006).

Situations, where material compositions and test conditions are used as neural network inputs, are ideal for polymer composite design. It is expected from a well-trained ANN to be helpful in estimating material properties before designing/testing real composites before producing them. ANNs can be helpful in simulating relationships between material performance and production parameters, which can be used to create a ground for computer-based production optimization. Analysis of the relationships between some simple properties and complex properties will be very helpful when designing new composite materials. Ordinary features are normally easier to obtain than complex ones, and therefore a successful prediction can be useful to mitigate the amount of complex experiments. The required number of training data can be reduced by optimizing the neural network architecture and choosing the appropriate input parameters. (Lefik et al., 2009).

Modern information approaches are used to check the level of damage detection based on fractographic images of materials. It is possible to construct frequency wave transform and convolutional neural networks and use the fractal dimension to assess the share of viscous and fragile results on damages. Fractal dimension, a value that identifies fractal structures or clusters based on assessing the level of the complexity, is one of the tangible indicators of metal structure and fractures. Today, the fractal dimension in image structures are explored by many programming languages. Detecting changes in refractive images or material structures is essential for accurately detecting fractal dimensions. Likewise, the crucial part in the assessment of microimages of material structures is the determination of the grain separation boundary. Today, ANNs are increasingly used for image description and classification. It is highly popular to use ANN and wavelet analysis in the examination and evaluation of the viscous and brittle fracture ratio of the specimen fracture surfaces after the bending test. This will increase the degree of use of fractography in the analysis of fractures and determine the direction of its destruction, and most importantly, it will eliminate the human involvement in computing the ratio of viscous and brittle components in the fracture. Also, it is essential to train ANNs on a wide range of fracture surface statistics. To detect the fractal size, operations can be performed by covering the digital image with a square cell mesh. Impact and bending tests can be performed for numerical analysis of metal fractures. Fractal dimensions can also be measured from the fractures of the samples. It is usual for the fractal dimensions of sample fracture to decrease relatively with increasing toughness. Studies using artificial neural networks where the fracture surface recognition error does not exceed 8%. This gives hope for the applicability of this method.

AI in Dynamic Mechanical Loads

The dynamic/mechanical features of short fiber reinforced composites were examined by Zhang et al. (Zhang & Friedrich, 2003). The storage modulus corresponds to the stiffness of the material under dynamic loading. High stresses induce microcracks that contribute to frictional damping. In fiber composites, different material components contribute to storage and damping properties in different ways. Although the increaed level of carbon fiber in composite material gives higher storage modulus, it also decreases the damping factor. The damping of polymer matrices varies with temperature, and a poor interface between the filler and the matrix will certainly increase the damping without a strong temperature dependence. Tensile, creep and relaxation tests were carried out using a PR2032 epoxy reinforced with fiberglass, carbon, and aramid, produced by the composite, laminate hand lay-up method, using a thermal chamber at different temperatures. Hence, satisfactory results can be obtained by evaluating all data with an artificial neural network. (Al Qadi, 2006).

Tribological Properties

Machine elements work under the effect of friction and wear. This necessitates lubrication and maintenance. The subject falls within the field of tribology. Two models are used in the tribological data analysis: empirical and phenomenological models. In the first, numerical relationships between tribological variables are assumed as predictions. In phenomenological models, numerical relations between tribological variables are used in continuum mechanics, fracture mechanics, thermodynamics, etc. It is developed from basic equations. The analysis of practical tribological experiments has been dominated by empirical models.

References

Ballard, D. H., & Brown, C. M. (1982). Computer vision (1. baskı). Prentice Hall.

Ballı, S., & Sen, F. (2014). Analysis of Damage in Layered Composite Plates Using Artificial Intelligence Techniques 8.

Bozuyuk, T.,Gokce, I.,Yagci, C., & Akar, G. (2005). Applications of Artificial Intelligence Technologies in Industry.

Califano, A., Chandarana, N., Grassia, L., D'Amore, A., & Soutis, C. (2020). Damage Detection in Composites By Artificial Neural Networks Trained By Using in Situ Distributed Strains. Applied Composite Materials, 27(5), 657–671. https://doi.org/10.1007/s10443-020-09829-

Cankaya, G., Arslan, M. H., & Ceylan, M. (2013) Determination of compressive strength of concrete by image processing and artificial neural network methods. Selcuk University Journal of Science and Technology, 1(1), 1–12.

Catbas, F. N., Susoy, M., & Frangopol, D. M. (2008). Structural health monitoring and reliability estimation: Long span truss bridge application with environmental monitoring data. Engineering Structures, 30(9), 2347–2359. https://doi.org/10.1016/J.Engstruct.2008.01.013

Chandrashekhara, K., Okafor, A. C., & Jiang, Y. P. (1998). Estimation of contact force on composite plates using impact-induced strain and neural networks. Composites Part B: Engineering, 29(4), 363–370. https://doi.org/10.1016/S1359-8368(98)00003-1

Copeland, B. J. (2022). Artificial Intelligence. Encyclopedia Britannica. https://www.britannica.com/technology/artificial-intelligence

Dabetwar, S., Ekwaro-Osire, S., & Dias, J. P. (2020). Damage Detection of Composite Materials Using Data Fusion With Deep Neural Networks (ss. 22–26). https://doi.org/10.1115/GT2020-15097

Dasgupta, A., Oyan, C., Barker, D., & Pecht, M. (1992). Solder Creep-Fatigue Analysis by an Energy-Partitioning Approach. Journal of Electronic Packaging, 114(2), 152–160. https://doi.org/10.1115/1.2906412

Di Scalea, F. L., Cappello, F., & Cloudt, G. L. (1999). On the Elastic Behavior of a Cross-Ply Composite Pin-Joint with Clearance Fits. Journal of Thermoplastic Composite Materials, 12(1), 13–22. https://doi.org/10.1177/089270579901200102

El Kadi, H. (2006). Modeling the mechanical behavior of fiber-reinforced polymeric composite materials using artificial neural networks—A review. Composite Structures, 73(1), 1–23. https://doi.org/10.1016/J.Compstruct.2005.01.020

Fekrmandi, H., Unal, M., Rojas Neva, S., Tansel, I. N., & McDaniel, D. (2016). A novel approach for classification of loads on plate structures using artificial neural networks. Measurement, 82, 37–45. https://doi.org/10.1016/J.Measurement.2015.12.027

Forsyth, D., & Ponce, J. (2003). Computer vision a modern approach (1. baskı). Pearson education.

Garrett, J. C., Mei, H., & Giurgiutiu, V. (2022). An Artificial Intelligence Approach to Fatigue Crack Length Estimation from Acoustic Emission Waves in Thin Metallic Plates. Applied Sciences, 12(3), 1372. https://doi.org/10.3390/app12031372

Grimaldi, D., Olivito, R., & Surace, L. (1998a). Damage evaluation in FRP composites by means of neural networks. Fifth international conference on composite engineering, 683–687.

Grimaldi, D., Olivito, R., & Surace, L. (1998b). Strain measurements in FRP composite materials by mean of neural networks. Proceeding of 11th international conference on experimental mechanics, 1411–1416.

Hajela, P. (2002). Soft computing in multidisciplinary aerospace design—new directions for research. Progress in Aerospace Sciences, 38(1), 1–21. https://doi.org/10.1016/S0376-0421(01)00015-X

Inik, O., & Ulker, E. (2017). Deep Learning and Deep Learning Models Used in Image Analysis. Gaziosmanpasa Journal of Scientific Research, 6(3), 85–104.

Japkowicz, N. (1999). Concept-Learning in the Absence of Counter-Examples:An Autoassociation-Based Approach to Classification. https://doi.org/https://doi.org/10.7282/T3J96B11

Kabaldin, Y., Anosov, M., & Shatagin, D. (2020). Evaluation of the mechanism of the destruction of metals based on approaches of artificial intelligence and fractal analysis. IOP Conference Series: Materials Science and Engineering, 709(3). https://doi.org/10.1088/1757-899X/709/3/033076

Klette, R. (2014). Concise Computer Vision: An Introduction into Theory and Algorithms (1. baskı). Springer London. https://doi.org/https://doi.org/10.1007/978-1-4471-6320-6

Lee, C. S., Hwang, W., Park, H. C., & Han, K. S. (1999). Failure of carbon/epoxy composite tubes under combined axial and torsional loading 1. Experimental results and prediction of biaxial strength by the use of neural networks. Composites Science and Technology, 59(12), 1779–1788. https://doi.org/10.1016/S0266-3538(99)00038-X

Lefik, M., Boso, D. P., & Schrefler, B. A. (2009). Artificial Neural Networks in numerical modelling of composites. Computer Methods in Applied Mechanics and Engineering, 198(21–26), 1785–1804. https://doi.org/10.1016/J.CMA.2008.12.036

Liu, D., Pons, D. J., & Wong, E. H. (2016). The unified creep-fatigue equation for stainless steel 316. Metals, 6(9), 1–18. https://doi.org/10.3390/met6090219

Liu, H., Liu, S., Liu, Z., Mrad, N., & Dong, H. (2017). Prognostics of damage growth in composite materials using machine learning techniques. Proceedings of the IEEE International Conference on Industrial Technology, 1042–1047. https://doi.org/10.1109/ICIT.2017.7915505

Molchanov, D., Safin, A., & Luhyna, N. (2016). Damage monitoring of aircraft structures made of composite materials using wavelet transforms. IOP Conference Series: Materials Science and Engineering, 153(1). https://doi.org/10.1088/1757-899X/153/1/012016

Morris, T. (2004). Computer vision and image processing (1. baskı). Palgrave Macmillan.

Nilsson, N. J. (2019). Artificial Intelligence / Past and Future (M. Doğan (Ed.); Second). Bogazici University Publishing House.

Oh, B. K., Glisic, B., Kim, Y., & Park, H. S. (2019). Convolutional neural network-based wind-induced response estimation model for tall buildings. Computer-Aided Civil and Infrastructure Engineering, 34(10), 843–858. https://doi.org/10.1111/mice.12476

Patro, S., Mahapatra, T. R., Dash, S., & Kishore Murty, V. (2021). Artificial intelligence techniques for fault assessment in laminated composite structure: a review. E3S Web of Conferences, 309. https://doi.org/10.1051/e3sconf/202130901083

Pidaparti, R. M. V, & Palakal, M. J. (1993). Material model for composites using neural networks. AIAA Journal, 31(8), 1533–1535. https://doi.org/10.2514/3.11810

Robinson, E. L. (1952). Effect of temperature variation on the long-term rupture strength of steels: American Society of Mechanical Engineers Transactions, v. 174. American Society of Mechanical Engineers Transactions, 74, 777–781.

Shapiro, L. G., & Stockman, G. C. (2001). Computer Vision (1. baskı). Prentice Hall PTR, USA.

Smith, R. A. (2009). Composite defects and their detection. Içinde Materıals Scıence And Engıneerıng -Volume III (ss. 103–143). Eolss Publishers Co. LTD.

Sonka, M., Hlavac, V., & Boyle, R. (2008). Image Processing, Analysis, and Machine Vision (3. baskı). Thompson Learning.

Stone, R., & Krishnamurthy, K. (1996). A neural network thrust force controller to minimize delamination during drilling of graphite-epoxy laminates. International Journal of Machine Tools and Manufacture, 36(9), 985–1003. https://doi.org/10.1016/0890-6955(96)00013-2

Su, Z., Ye, L., & Lu, Y. (2006). Guided Lamb waves for identification of damage in composite structures: A review. Journal of Sound and Vibration, 295(3–5), 753–780. https://doi.org/10.1016/J.JSV.2006.01.020

Todoroki, A. (2001). The effect of number of electrodes and diagnostic tool for monitoring the delamination of CFRP laminates by changes in electrical resistance. Composites Science and Technology, 61(13), 1871–1880. https://doi.org/10.1016/S0266-3538(01)00088-4

Vandoni, C. E. (1996). Proceedings: 1996 CERN School of Computing : Egmond Aan Zee, The Netherlands, 8 September-21 September 1996 (C. E. Vandoni (Ed.); 8. baskı). CERN.

Xu, J., Wang, W., Han, Q., & Liu, X. (2020). Damage pattern recognition and damage evolution analysis of unidirectional CFRP tendons under tensile loading using acoustic emission technology. Composite Structures, 238, 111948. https://doi.org/10.1016/J.COMPSTRUCT.2020.111948

Zadeh, L. A. (1983). The role of fuzzy logic in the management of uncertainty in expert systems. Fuzzy Sets and Systems, 11(1–3), 199–227. https://doi.org/10.1016/S0165-0114(83)80081-5

Zhang, Z., & Friedrich, K. (2003). Artificial neural networks applied to polymer composites: a review. Composites Science and Technology, 63(14), 2029–2044. https://doi.org/10.1016/S0266-3538(03)00106-4

Zhao, G., Zhang, G., Ge, Q., & Liu, X. (2016). Research advances in fault diagnosis and prognostic based on deep learning. 2016 Prognostics and System Health Management Conference (PHM-Chengdu), 1–6. https://doi.org/10.1109/PHM.2016.7819786

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Kayrici, M. & Dogan, A. F. (2022). Damage Analysis Using Artificial Intelligence Techniques on Composite Materials, Y. Uzun. & R. Butuner (Eds*.), Current Studies in Artificial Intelligence, Virtual Reality and Augmented Reality* (pp. 89–107). ISRES Publishing