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Structural Health Monitoring (SHM) System for Polymer Composites: A Review

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Abstract

Objectives: The main objective of this paper to review the various currently available Structural Health Monitoring (SHM) systems for the Polymer Composites particularly in aviation industries. **Methods**: This paper provides a complete overview about the various types of damage detection technique currently used for the polymer composite structure and also highlights the concept behind the each technique. A brief overview of the research work on experimental and theoretical studies on the various SHM systems is considered and several research papers on these topics are cited. This paper reviews various recent advancement made in the field of damage monitoring techniques, particularly the Piezoresistivity technique with the advent of nanomaterials. **Outcomes:** This paper serves as an effective source of literature for those interested in pursuing research in the Structural Health Monitoring (SHM) System for the polymer Composites. This paper also provides an effective source of information about the possible research gap in the field the SHM.

Keyword: Composite Materials, Fibre Bragg Grating, Nanomaterials, Piezoresistive Method, Structural Health Monitoring (SHM) System

1. Introduction

Today, Composite materials are increasingly being used in various industries, primarily for lightweight application such as aircraft structures. The composite materials are continuously replacing the metals because of their superior properties such high stiffness, high strength, prolonged life and high resistance to corrosion. The composite material is an advance engineering material contains two or more different materials (reinforcing and matrix); whose bulk properties show significantly improved behavior when compared to the individual constituents. Many common engineering materials such as polymers, filled ceramic, metals and its alloy are also have certain amount of particle dispersed in their final compound structures. However, such dispersed materials are not considered as the composite materials, because their bulk properties are very much similar to those of their base materials, for example, Steel and iron has similar physical properties. The favorable advantage of modern engineering composite materials is light weight, high strength and stiffness, improved corrosion resistance, etc.

The concept of composite materials is invented by the nature, not by a human being. An example for natural composites is wood, invertebrate's shell. In ancient India, husks or straws are used as short fiber reinforcement with clay to improve the mechanical strength of the clay, which showed improved behavior for several hundred years. Lightweight structures based on fibre reinforced composite offer many advantages in the design of material and energy efficient components in comparison to conventional structures. The implementation of lightweight structures is therefore a leading trend, especially in mobile application areas like aerospace, marine etc.

Unlike conventional metals, the composites are anisotropic or orthotropic materials, where the material properties are different in different directions, when subjected to different loads. Hence, the damage in the

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composite materials is difficult to predict, which in turn reduces the safety of the composite structure and furthermore, it requires exceptionally definite damage assessment before getting into the operation especially in aviation industries. Hence, in order to make the composite safer, we need to continuously monitor the composite for damage and failure. A system, which continuously monitors the composite structure for damages and failures, is simply called as Structural Health Monitoring (SHM) system.

The Structural Health Monitoring (SHM) is a system, which detect the various kind of damage and failure induced in the structure, also interpretation and assessment of the damage induced in the engineering structure in order to improve its reliability[1,2]. Simply integration of a non-destructive evaluation system into a structure for damage and failure prediction in the structure is called the SHM. On the whole, the SHM improves the life of the structure and also reduced the life cycle cost of the engineering structure. Out of various industries, particularly aircraft industry pays lum some for their routine maintenance. Because of anisotropic nature of the composite materials, the maintenance and the damage prediction of the impacted surface are very hard to perform, since most of the damage induced in the structure may invisible in nature[3–5]. Currently, various kinds of sensors are attached to the composite materials to measure the on board stress and strain induced in the composite materials. These embedded sensors provide various useful data about the damage and failure state of the composite materials used in the aircraft.

The Structural Health Monitoring (SHM) of the composite materials involves intergradations of networks of sensor or sensing element within the composite structures for prediction, localization, assessment and evaluation of various damage induced in the composite materials[6,7]. The various sensors such as the metallic strain gauges, metal oxide films, doped semiconductors[8,9], piezoelectric sensors[10,11], optical fibre sensors[12–15], Eddy-current sensors[16,17], acoustic sensor[18,19] and magnetostrictive sensors[20] for damage and failure prediction in the composite materials. All of these sensors have their own advantage and disadvantage which limits their application and sensitivity.

In this paper, a detailed review on the various state of the existing art of technology with broader focus on the SHM system for the polymer composite materials used in particularly, aviation industries is presented. The various sensing materials with detailed focus on sensing, data collection and processing techniques are also discussed. The primary purpose of this paper is provide various state of art of technology available up to date and also to provide detailed background on the SHM for composite structure used particularly in aviation application. In this paper, the various materials, sensing method and technology in the field of the SHM for the composite materials are described briefly with more emphasis on recent advancement in the field of the SHM particularly for the composite materials. More detailed focus is then dedicated to Resistive Methods, Fiber Bragg grating and more specifically Carbon Nanotubes (CNT) based resistive method.

2. State of the Art Structural Health Monitoring (SHM) System

2.1 Piezo-Resistive Method

The electric resistive method was initially used for the purpose of strain and damage sensing in the structural health monitoring for Carbon Fiber Reinforced Polymer (CFRP) composites, by means of measuring and monitoring the fractional change in the electrical resistance of the embedded carbon fiber[21,22]. Many research studies have then employed the electrical resistive method for such purposes in the SHM for the polymer composite materials. In a series of work, possibly in situ damage detection technique is developed for unidirectional Carbon Fibre Reinforced Polymer (CFRP) composite by means of electric resistance and capacitance measurements for the identification of various damage induced in the composites, by in terms of fibre failure and matrix failure by the use of DC and AC electricity[23,24]. Under monotonic and cyclic flexural tests, the strong change in the resistance and capacitance are observed during the development of damage. The fractional variation in the electrical resistance and the capacitance, which due to the variation in the electrical conduction paths in the composites are directly, linked the damage induced in the composites during real-time loading. The fiber failure can be assessed by the DC conduction path, where as the matrix failure can be predicated using AC capacitance measurement. Hence with this conduction path, it is possible to predict the real-time strain and failure and also it is possible to classify different failure mechanisms of the composite under real-time static and dynamic loading conditions using resistive and capacitive methods[25].

The fatigue damage of the composite materials in terms of reduction in the residual strength and stiffness are measured in terms of change in electrical resistance using carbon fibre as sensing element[26]. They also found that the change in stiffness and electrical resistance during fatigue tests are in a similar trend. This is because the cumulative fatigue damage is represented by the degradation of residual stiffness and these damages are causing a change in electrical resistance, which can directly correlate with the degree of damage in the composites. The SHM system is developed for GFRP composites by means of measures the fractional change in the electrical resistance of the embedded sensing element in the composite materials, which considerably improves the reliability of the composite materials[27]. In this study, both Carbon fibre and Carbon powder are used for sensing purposes. In term of sensing capacity, the carbon powder reinforced GFRP composites are showed superior behavior, when compared to carbon fiber reinforced GFRP composites[28]. In another work, a model is proposed by taking account of fibre breakage due to tensile strain to describe the fractional change in electric resistance in the fiber direction[29].

In a series of works, an electrical resistive method for detection of cracks and damage is employed in composites using carbon fibre and graphite as sensors[30–34]. The electromecanical study reveal that the volume fraction of fiber play a promising role in the electrical conduction on both transverse and thickness direction and also with this semiconducting nature, the variation in the electrical conduction can be correlated to the delamination induced in the composite under real-time loading. For composite laminate with high volume fraction of fiber, the spacing of the electrode plays an importance role in prediction behavior for delamination size, intensity and location of the composites[35].

A two-dimensional SHM system for the composites is proposed in a study using network of electrical resistance in the laminate to predict the fractional change in the electrical resistance in the composite due the real-time uniaxial tension loading[36]. The piezoresistance behaviour in the longitudinal direction (fiber) and trough thickness is measured based on the probabilistic failure model using conduction path parallel and perpendicular to the fiber size and they found that the variation in the piezoresistance of the composite varies linearly for small stain. At the same, the variation in the piezoresistance is varied nonlinearly with respect to high strain[37]. In another work, a two-dimensional model is proposed to predict the variation in the electrical resistance of the composite under uniaxial tension at different temperature with temperature compensation factor[38].

By measuring the variation in the electrical resistance of the composite, the strain induced in the composite with respect to the applied load can be correlated for the Carbon Fiber Reinforced Plastics (CFRPs) composite[39]. The piezoresistive study reveal that any misalignment in the laminate structure will cause large shrink in the through thickness direction, which ultimately reduce the overall tensile strength of the composite and also poor electrical conductivity in the through thickness side will considerable increases the current, which reduce the overall electrical resistance of the composite in that direction. The electromechanical behavior of piezoresistive carbon filament yarn as the strain sensor is proposed for fiber reinforced composite structures[40,41]. The integration and characterization of piezoresistive carbon filament yarn in thermoplastic composites has been realized for unidirectional fibre reinforced composites[42] and knitted demonstrator[43]. In another work, under flexural fatigue cyclic loading, the electrical resistance of the Carbon Fiber Reinforced Carbon Composite (C/C Composite) change irregularly and this irregularity is correlated with various stress level induced in the composite structure[44].

A new diagnostic technique for impact damage in the composite is proposed, which is based on the piezoresistive of the composites[45]. The impact damage considerable increases the fiber-fiber contact at interlanina interface, which considerable again reduces the overall electrical resistance of the composites. The damage induced in the composite, will make the current to get concentrate around the damage, which considerable cause intense resistive heating around the damage area. The resistive heating in the damage area will cause temperature difference, which will be measured by the thermography technique. With this temperature difference the damage accumulation in the composite can be directly correlated.

In another work, a new structural health monitoring system for carbon fiber reinforced composite is proposed, where the damage induced in the composite is correlated with the variation in the electrical resistance of the carbon[46]. The Piezoelectric Fibre Composite Transducer (PFCT) based health monitoring system for composite is developed and characterized[47]. In this study, two different types of piezoelectric fiber composite transducers such as Macro Fibre Composite (MFC) and Piezoelectric Fibre Composite (PFC) have been calibrated for embedded sensor by investigating their sensor performances based on the various characteristics feature such as noise levels, resolution, irregularity and sensitivity. They found that each fibre used in the study has significant advantage in specific parameters.

A continuous monitoring system for thermoplastic composite structures using textile process technologies is developde[48]. They designed and integrated one dimensional and two dimensional sensor structures based on the carbon filament yarn in tee fiber reinforced composite materials for damage detection. In this work, the carbon filament yarn is used as the sensing element in thermoplastic composites. The change of resistivity in consolidated textile reinforced composites is measured using the Wheatstone's bridge principle, while the tensile loading is applied uniaxially. The resistance value of carbon filament yarn changes with respect to the applied load is measured which is directly correlated to the damage in the composites.

In another work, a new load and damage monitoring concept is proposed for the composite structure using in-situ piezoelectric sensor signals. The embedded piezoelectric sensor will monitor the fractional variation in the loading path of the composite structure using approximate numerical compensation techniques, which will considerable address the relationship between the load and the piezoelectric sensor's characteristic[49]. In another work, the interlaminar delamination in the Glass and Carbon fiber reinforced composite is predicted using CNT fiber yarn[50].

The present advancements in the field of nanotechnology have paved various new frontiers for piezoresistive sensor applications[51]. Because of the unique characteristics of this new nanomaterials such as CNT, made it highly potential for the development of cost effective and high sensitive strain sensor solution for the SHM particularly for composite materials[52–55]. Over the past decade, the carbon based nanoparticles such as activated carbon powder, carbon fiber, carbon wire; single wall carbon nanotube, multiwall carbon nanotube, graphene etc., are extensively studied.

In a series of studies, Poly Vinyl Alcohol-Carbon Nanotube (PVA-CNT) fiber is embedded into the Glass fiber reinforced Polymer composite with potential aim to measure the real-time strain induced in the composite for the purpose of the Structural health Monitoring System[56–58]. The embedded PVA-CNT fiber act as strain sensor, which will measure the strain in terms of variation in the piezo-resistance of the fiber. The fractional change in the piezoresistance of the embedded PVA-CNT fiber is correlated to the corresponding strain induced in the polymer composite under uniaxial loading. Also they pre-stretched the PVA-CNT fiber before embedding into the polymer composite and electromechanical investigation revealed that the pre-stretching of the PVA-CNT fiber embedded in the polymer composite increases the efficiency of the strain sensing. The specific reason behind the increasing of efficiency of the pre-stretching of the PVA-CNT fiber is due to the higher order alignment of CNT in the PVA.

In another work, Carbon Nanotube (CNT) fibers are embedded in reinforced polymer composites for the purpose of strain sensing under structural health monitoring system[59]. Under real-time loading, the embedded CNT fiber acts as a strain sensor. From the electromecanical characterization of the embedded CNT fiber, a direct correlation between real-time strain induced in the composite and the fractional variation in the piezoresistance of the CNT fibers can be established.

In another work, the electrical conductivity is induced in the insulating epoxy resin by modifying the epoxy resin by addition two different type of conductive fillers such Carbon Nanotube and Black carbon with potential application for the strain sensing[60]. Nanomaterials based a novel multi-modal sensor is developed to measure the real-time strain induced in the composite under the aim of the structural health monitoring system for composites[61]. The Carbon Nanotube (CNT) is coated on the glass fibre, which is then incorporated into glass/epoxy composites as the sensing element. The CNT growth on glass fibre (fuzzy glass fibre) is carried out using the chemical vapour deposition process. The electromechanical investigation revealed that the Carbon Nanotube (CNT) coated glass fiber (fuzzy fiber) sensors exhibits more or less similar sensitivity in term so measure the real-time strain induced in the composite, when compared to the conventional strain gauges and also these CNT coating based sensor offers simple and effective integration into the polymer composite materials as the strain sensor.

In another study, the piezoresistive behavior of the embedded Multi Walled CNT based flexible thin films is investigated[62]. They embedded multiwalled CNT into the Poly Methyl Methacrylate (PMMA) matrix to monitor the damage and failure of the composite in terms of piezoresistance variation. The mechanical characterization revealed that the addition of Multi walled

CNT considerable increases the tensile properties and also offers the highest piezoresistive sensitivity at the percolation threshold. In another work, same Multi Walled CNT are made into thin film using polystyrene as binding medium and the piezoresistivity behaviors study revealed that these Multi Walled CNT/polystyrene film can offer a Gauge Factor (GF) of about 3.28 at 6% weight concentration and about 1.49 at maximum of about 10% weight concentration of MWCNT in polystyrene composites[63]. Whereas in another work, the gauge factor of about of 15 is obtained for 1% weight concentration of Multi Walled CNT in PMMA matrix composites[64].

A new damage and failure monitoring system for polymer composites is developed using Single-Walled Carbon Nanotube (SWCNT) based thin film for measuring the strain induced in the polymer composite under different loading condition such uniaxial tensile, compression and bending[65,66]. The new SWCNT based 1D fiber sensor are embedded into the polymer composite for the purpose of mapping the real-time strain and stress induced in the composite due to externally applied load. This 1D SWCNT fiber sensors are embedded into the polymer composite at predetermined location and orientation to acts multipurpose sensor for the purpose of the structural health monitoring system (from manufacturing to failure) of the polymer composites. In another study, the characteristic features and usefulness of the 3-dimensional (3D) distributed CNT sensing elements for the damage and failure purpose in the glass fiber reinforced composites is studied[67–69].

In a series of works, the usefulness of CNT as a embedded sensors to measure and monitor the initation and propagation of microcrack induced in the polmer composite materials is demonstrated[70,71]. A CNT based strain sensor is developed and investigated the various processing parameters on the strain sensing capabilities[72]. The experimental and numerical investigation revealed that the tunnelling resistance highly influence the sensitivity of CNT/Polymer strain sensor under tensile and compression load. With the glass fibre as substrate, various deposition technique such as Chemical Vapour Deposition (CVD) and electrophoretic deposition method are employed to fabricate the CNT deposited 1D fibre sensors and also explored the applicability of these deposited 1D CNT fibres as a embedded sensors to evaluate the damage induced in the polymer composites[73]. In another work, the Comparison between ultrasonic C-scan and the electrical damage mapping for a majority of the nanomaterials filled specimens is investigated and established the reliable correlation fro delamination locating in the glass fibre reinforced composites. The modification of polymer composite with different nanomaterials and aligment of nanofillers in different oreientration resulted in a significant variation of the sensitivity of the damage prediction in the composites[74].

In another work, it is found that the sensitivity of the filled composite relied mainly on the filler concentration, that is high filler concentration showed least sensitivity and low filler concentration at near percolation threshold showed maximum sensitivity to the strain and damage measurement[75]. Another damage mapping technique is proposed for the polyer composite, where CNT is grown on the alumina fibre to measure the damage induced in the polymer compostes[76].

2.2 Fibre Bragg's Grating

A wide range of embedded and surface mounted sensors has been used for damage monitoring applications. The various kind of sensor such as metallic thin foil strain gauges, fiber optic sensors, microwave and ultrasonic sensors, accelometers, acoustic sensors and other wireless sensors, etc., are extensively used for SHM purpose. Among the other sensor, the fiber optic sensor has been extensively used and emerged as real-time strain and damage sensor for SHM due to their unique advantages such as sensitivity and multiplexing capability.

Fibre Bragg's Grating (FBG) sensors are the special spectral filters, which work based on the principle of Bragg reflection. In Fiber Bragg's Grating, the gratings are nothing but a series of parallel lines, which printed close together in the inner core of the optical fiber. When this gratted optical fibers are exposed to a periodic pattern of ultraviolet light, the special diffraction spectra is obtained, which contains alternating regions of high and low refractive indices. When this grated fiber are subject to load, which considerable induced strain in the grating pattern. This change in grating pattern will considerable varies the diffracted spectra. Thus from the variation in the diffracted pattern, the strain induced and corresponding load acted on the structure can be easily correlated[77–79].

In most of the recent works, Fiber Bragg's grating has been extensively used for damage and failure prediction in the composite materials. A wide range of experimental studies has been focused on the feasibility and performance evaluation of Fiber Bragg's grating sensors embedded in laminated composite structure[80]. In most of the work, the Fiber Bragg's grating sensor is embedded into the laminate composite structure for real-time strain and damage predication system for composites. The Fiber Bragg's grating sensor is evaluated under cyclic loading condition for its accuracy, reliability, repeatability and fatigue parameters[81].

The dynamic feature of two steel bars joined structure is detected by the FBG sensors for damage, which are artificially in the structure before testing[82]. The FBG sensor showed response, which are so close to the response collected from the conventional accelerometer. In another works, the FBG sensor is used to measure the dynamic strain induced in the offshore structure under seismic excitation and compared the result with conventional strain gauge[83]. The feasibility study of the FBG sensor is carried out to integrate into a composite tube structure to detect the strain changes under loading[84].

In another works, an experimental study is carried out integration of FBG sensors into repaired composite panels, which are used in aircraft for size, location and nature of fatigue crack induced in the bonded region[85]. The identification of fatigue damage in the bonded region is carried out by compared the reflection spectrum obtained from the damage and undamaged repaired composite panel. By comparing the optical spectra obtained from the FBG sensor embedded in the repaired composite panels, the location, size and damage degree of fatigue cracks induced in the composite panel is identified. In another work, fiber optic sensors are used to analysis the composite wing beam for dynamic feature to predict the damage and failure of the composite wing[86].

In another wok, the FBG sensor are used to predict the damage and failure such as delamination, debonding of the composite structure by monitoring the strain response of the composite structures and any sudden changes in the strain is correlated to the damage of the composite strucutre[87]. In a study, the vibrational mode analysis is suggested to predict the damage and failure of the composite panel when subject to loading[88]. From the vibrational response of the composites, author calculated and correlated the various mode damage and failure induced in the composite panel.

In another work, the Draw Tower's based FBG sensor are embedded into a carbon reinforced polymer composite cantilever beam for evaluation of damage in the beam. The damage such as delamination and debonding in the composite bean is calculated based on shifts in resonance frequencies of the FBG sensors[89]. The reliability of embedded and surface attached FBG sensors on the thermoplastic composites for SHM purpose is studied in detailed[90]. The embedded FBG sensor showed more realistic strain response, when compared to the extensometer measurements under fatigue testing.

In another work, a novel low-pressure FBG sensor is proposed. In this novel work, the FBG is embedded partially into a polymer-filled metal tube. The partial embedment of the FBG showed enhanced sensitivity on the pressure measurement[91]. The strain monitoring reliability of Fibre Bragg Grating Sensor (FBGs) and optical fibres in composite structures is assessed[92]. Optical fibre and FBG embedded in the composite structure provided continuous information about composite structure's integrity. However, the ultimate tensile strength of the composites decreases to an extent due to the embedded FBG and optical fibres.

In another work, a long Fiber Bragg Grating (FBG) optical sensor is used to measure the dynamic response of the composite materials used in aerospace structure. The long gauge FBG sensor are used to predict the real-time strain and image induced in the composite materials under real-time loading[93]. In another work, the feasibility study on embedded Fiber Bragg Grating optical sensor to understand the loading and failure behavior of the various civil structures under different extreme loading cases[94].

In another work, an intelligent SHM is proposed for aircraft structures using four Fibers Bragg Grating sensor (FBGs). In this intelligent system, the digital signal processing techniques such as Support Vector Machines (SVM) and as Discrete Wavelet Transform (DWT) are used[95]. Out of two advanced signal processing technique, support vector machines technique showed promising response using nonlinear kernel. In another work, the FBG sensor system is embedded into thin composite laminates for SH purpose[96]. Conventionally, in FBG optical sensors uses 1550 nm wavelength, however in this work utilized the FBG sensors in the Near Infra-Red (NIR) range 830 nm.

The reliability of Fiber Optic Ribbon Tape (FORT) concept is studied to measure and monitor the real-time strain induced in the composite materials under prolonged cyclic loading and also for accuracy and repeatability of real-time measurement[97]. The FORTs are nothing but pre-assembled composite ribbon tapes, where the optical fiber is embedded in between the two composite lamina. The main advantage of the FORT assemble is for easy mounting and handling of optical fiber and also for protection from atmosphere degradation. The strain measured by the FORT tape showed better accuracy result than the conventional optical fibre.

A fiber optic polarimetric sensor is developed for prediction the dynamic response from the laminated composite during impact loading condition. Three different types of fibers are embedded into the laminated composite structure of measure and monitor the dynamic response is studied[98]. In another work, a feasibility study of fully distributed vibration sensor is carried out real-time strain measurement and monitoring purpose[99]. In another work, Polarization Maintaining photonic Crystal Fiber (PM-PCF) based SHM for a composite beam is investigated. The experimental investigation revealed that the PM-PCF is more attractive sensor for damage prediction purpose, because of its unique vibration properties[100].

In recent days, the research on the multi-materials system has attracted more focus on the field of the Structural Health Monitoring (SHM). Numerous researches have been done to develop and evaluate the feasibility of the concepts for integration of multi-materials system for smart sensing in the composite materials[101–105]. In a recent work, multi-materials based strain sensor is developed to measure and monitor the real-time strain and damage induced in the composite structure[106]. Multi agent system seems very reliable and efficient for the larger composite laminates, where different types of sensing elements are used for various damages. The most important advantage of multi agent system is wide coverable for various modes of failure and damage, because it consists of different type of sensor for various damages. Also the uniformly distributed sensor and its network can deal and fuse various kind of information about the failure and damage induced in the composites structure.

Recent development of Micro Electro-Mechanical Sensors (MEMS) hailed the SHM for composite materials because of its easy handling, tiny size and negligible weight. In the Micro Electro Mechanical Systems (MEMS), the mechanical and electrical sensing element is combined together in a single silicon chip at micro scales. After the invention of MEMS, considerable efforts have been made toward development and integration of MEMS into composites structures for health monitoring purpose[107]. A local transmissibility vibration-based diagnostic algorithm based Structural health monitoring system for aircraft structure is proposed, which use smart wired piezoelectric arrays of accelerometers (MEMS) as sensor[108].

A new robust SHM system for the composite materials is developed using meta-stable ferrous alloy as a sensing element. Inserted strain memory alloy provided an indication about the significant change in magnetic susceptibility during the tensile loading over the composite materials, which can directly correlated to the damage induced in the composites[109]. A new Micro Electro-Mechanical Sensors (MEMS) based crack monitoring system for composites is proposed[110]. Under cyclic loading condition, surface mounting MEMS tracked the propagation of the microcracks or delamination induced in a double cantilever beam and monitored the path and intensity of microcracks propagated in the composite materials. Advanced MEMS based SHM for the composite tower is proposed[111]. In another work, a MEMS-based damage monitoring system for the laminated composite structure is investigated for the effectiveness and robustness[112]. The effectiveness and robustness have been evaluated based on the sensitivity of the sensor, which mounted on the surface of the composite materials to the size of the delaminated region and repeatability of results respectively.

In another work, a damage prediction algorithm, which is based on the signal collected from the clock-like configuration of the PZT transducer as sensors are presented, by taking advantage of spectral element method and Lamb waves[113]. A new health monitoring system for aircraft wing is presented, which is based on the Guided Lamb waves, where transducers is used as active sensors and secondly using acoustic emission sensors as passive mode for continuous monitoring using same transducers[114].

In another work, multi-response Material Removal Rate (MRR) and Surface Roughness (SR) using Box - Behnken method was employed for Al composites to predict the various health parameters of the Al composites using Radial Basics Function Neural Network (RBFNN) and Artificial Neural Network (ANN) techniques[115]. Health monitoring of concrete structure was performed with embedded carbon fiber into the concrete structure[116].

Apart from the above mentioned technique, several other techniques have been successfully used in the SHM for composite materials. Numerous literature reviews have been made to foresee the theoretical concept and its applicability. Various Structural Health monitoring techniques and its backup concept are reviewed for the year 1996 to 2001[117]. In another work, for composite materials, the vibration based damage monitoring system is reviewed with special emphasis on concept and methodology[118,119]. A detailed review about the Guided Lamb wave technique for failure identification and monitoring in composite structures is presented[120]. Various wireless sensor and sensor network used in the SHM purpose for composite materials are reviewed[121].

From the above detailed literature survey, it can be observed that there is a lot possible research gap and unsolved questions in the field of the SHM system, even though the advent of advanced nanotechnology, particularly for composite materials. Specifically, the most of the recent work focuses only about the in-suti measurement of the real time strain induced in the composites. However, limited focus was made on the damage severity, location of damage and residual strength of the damaged composites. To be a better Structural Health Monitoring system, it should provide not only real-time strain, but also degree of damage and residual strength of the damaged composites. Also, the SHM should provide information about the various modes of failure occurred in the composites such as delamination, fiber pullout, matrix failure, etc. Hence, the future research should focus more on the damage assessment, failure mode prediction and residual strength evaluation of the damaged composites, in order to fulfill the purpose of the SHM System for the polymer composites.

3. Conclusion

This paper has reviewed the topic of Structural Health Monitoring (SHM) System, including Resistive Methods and Fibre Bragg grating and well cited the theoretical and experimental work conducted related to SHM for composite materials.

Structural Health Monitoring (SHM) System for the composite materials is one of the key technologies in the composite industry. It is a challenge task to develop a new suitable SHM for composite materials and its structures used in aircraft because of the hostile and unpredictable service environment. A lot of notable progress on SHM has been made by ceaseless efforts. However, the existing Structural Health Monitoring (SHM) cannot completely fulfil the requirements for composite damage detection in real time application. Hence, the future research should focus more on the damage assessment, failure mode prediction and residual strength evaluation of the damaged composites.

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