

Review Article

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Interfacing the IoT in composite manufacturing: An overview

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Abstract: It is a well-known fact that many sophisticated works consume a lot of human resources, leading to the need to find effective alternative. The manufacturing industry demands a lot of human resources, with around half of the global working population participating in this sector. Challenges such as sudden conflicts in the data, disasters, and loss of productivity are encountered by the manufacturing industries and can be overcome by monitoring machine performance data and automatically configuring the machines according to changing needs. This emphasizes the importance of the Internet of Things (IoT) in addressing niche areas of manufacturing. IoT is a buzzword heard everywhere around the globe. Implementing this technology makes most of the work more accessible than other conventional methods. This has created a lot of research interest on this topic. Among many manufacturing sectors, polymer composite material manufacturing is one of the most demanding. This review article purely focuses on polymer composite manufacturing and its allied processes. The consolidation of data is based on the influence of IoT on the extraction of fibers and manufacturing of polymer composite material using novel techniques, quality assessment of manufactured polymer composite material, challenges faced in exploring the use of IoT, and future scope. It can be stated from the survey that various researchers have minimally explored the incorporation of IoT, but its future looks very promising in terms of producing high-quality products at less time and lower cost by integrating this technique with conventional methods.

Keywords: IoT, composite manufacturing, additive manufacturing, quality

1 Introduction

Composite material is a material that combines the characteristics of two or more constituent elements [1]. In the end, the composites are stronger and lighter than the original material. Because of their numerous benefits and one-of-a-kind characteristics, composites have found widespread use across countless companies, with the worldwide composites economy estimated to rise \$113.2 billion through 2022 [2]. Fiber-reinforced polymer (FRP) composite materials have been used in marine, aerospace, construction, as well as automotive industries, and nowadays 50% of the Boeing 787 airplane material content is composites [3]. In addition, Airbus expects a rise in carbon fiber supply of about 20,000 tonnes by 2020 [4]. FRP composites, notwithstanding their major benefits, are vulnerable to complex deficiencies during production, assembly, or wear and tear in service [5,6]. Deformations, de-bonding, delamination, and fiber breakage are the most common causes of in-service defects [7,8]. These flaws can result in permanent failure if they go unnoticed. As these deficiencies must be identified and the threshold restrictions determined to avoid such malfunctions, it is essential to do so [9,10]. The Federal Aviation Administration recognized the significance of a serious damage-specified tolerance inside its aircraft accreditation directives [11].

In addition, an *in situ* structural health monitoring (SHM) framework could indeed be used to diagnose as well as evaluate damage. To consistently diagnose and supervise the wellness of structures, the SHM system combines sophisticated sensing devices with post-processing methodologies [12–15]. However, it is hard to adopt SHM because of the extra weight and the cost of the equipment. When an aircraft has an SHM system installed, the highest landing weight would then increase, resulting in a decrease in operational cargo. The reduced cargo capacity reduces the number of people, which in turn reduces income [16].

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Lightweight sensors with high identification limits seem to be preferable to ensure the practical implementation of SHM methodologies. Even though nondestructive testing (NDT) and SHM seem to be essentially numerous strategies, recent advancements in smart sensors and post-processing methodologies have made these contrasts less distinct [17,18]. To guarantee that NDT and SHM techniques can be seamlessly integrated for functional composite material applications, it is important to understand recent developments across NDT&E and in SHM techniques for critical damage categorization [19,20].

The Internet of Things (IoT) is an emerging technology that connects humans, machines, and materials through a common artificial intelligence platform. This technology oversees the data collection, data analysis, and decision-making regarding the process parameters involved in the production of various commodities [21,22]. Composite materials are the state-of-the-art materials that are the replacement for monolithic materials. Their quality solely depends on the raw materials used for manufacturing them and the method of manufacturing. To directly control the quality of the composite material, the involvement of IoT can be readily considered [23–25]. The entire survey reveals there is scope for digital technology in manufacturing, not only in health monitoring but also in other diverse areas such as the production of composites and data analysis for quality of manufacturing. In the following sections, we will discuss composite manufacturing and its quality assessment with the aid of IoT.

2 Extrudable FDM-based composite

A few works addressed a versatile material additive manufacturing (AM) technique comprising using an extruding nozzle that can move together across one or more axes while simultaneously dispensing one or many filaments. In this method, the filament is encased inside or through an extrudate fabricated by the nozzle. When the filament is delivered, it is principally coaxial well with an extrudable substance, resulting in an encapsulation. The filament is a conductive thermoplastic polymer, semiconductor, ceramic, coaxial cable, conductor, conductive polymer, optical fiber, magnetic material, fiber, tube, synthetic or natural thread, metal, or conductive powder. One or more filaments are wound into coils, formed into blocks, cylinders or other shapes to form various actuators, sensors, thermal management structures (*e.g.*, using wire and/or a composite containing metal or boron nitride particles), chokes, switches, resistors, supercapacitors, fuses, inductors, capacitors,

transformers, antennae (*e.g.*, patch, fractal), variable-resistance resistors, external connecting pads, batteries, temperature sensors, pressure sensors, force sensors, capacitor plates, heat sinks, solenoids, cores and armatures for electromagnetic devices, heat conduction structures, or power supplies [26–28]. Another aspect of some studies focused on a versatile material AM technique comprising a first extruder for extruding an extrudable material; a filament, fiber, or wire dispenser that extrudes one or more filaments, in which the extrudate from the nozzle is encased in the extruded filament. For example, the filament is fabricated nearly coaxially only using a thermoplastic substance in various configurations. The filament is produced nominally by the coaxial extrusion of the thermoplastic substance [29,30].

2.1 Fiber-encapsulated AM

Fiber-encapsulated AM (hereinafter mentioned as FEAM; previously termed as 3D polymer + wire printing, or called 3dPWP) technique, system, and apparatus proposed in this work deliver a versatile material AM technique that can produce workable electromechanical devices by using a polymer along with a wire. More generally, the polymer may be another nonpolymeric material such as a ceramic, whereas wire may be a tube, a solidifying liquid, or another element, fiber, or filament of any composition. The term “polymer” encompasses all constituents extrudable through a nozzle and solidified by UV curing, thermal curing, evaporation, cooling, and so on. Similarly, the term “wire” includes a wire (*e.g.*, metal wire) as well as any fiber and or filament including polymer fiber, carbon fiber, small-diameter tubing, glass fiber, and all other constituents and edifices possessing a filament or fiber-like shape [31,32]. These constituents may be monofilament or hold many strands, occasionally impregnated along with detained together with the help of resin similar to pre-preg used in composite production. FEAM significantly encompasses AM to enable the automated fabrication of multifunctional components, devices, and multi-material structures, including inductors, fuses, actuators, sensors, transformers, resistors, thermal management structures switches, antennae, embedded 3D circuitry, and capacitors, among other elements [33,34].

The co-deposition of fiber and combined resultant substance is the foundation of the FEAM process, which encapsulates the fiber while jointly depositing it. This feature alone allows for a wide range of products to be created. In addition, the FEAM process has additional capabilities that make it more versatile, such as stopping and starting a fiber (*e.g.*, using a nozzle as described later), forming

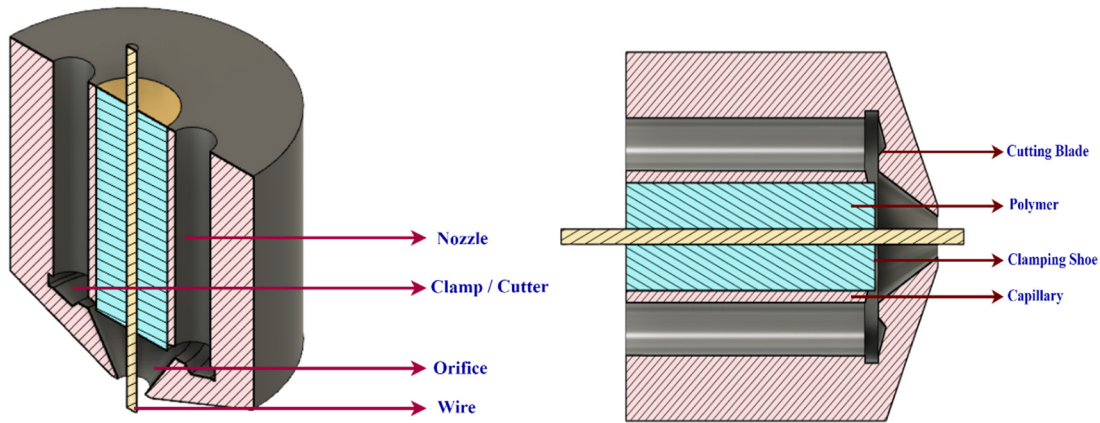


Figure 1: Schematic representation of segmenting and feeding a fiber composite [42].

junctions between fibers that allow electric currents (or in some representations electro-optic signals) to flow from one fiber to another, linking fibers structurally so that stresses can be transferred from one fiber to another. The homogeneous manufacturing of perfectly functioning products and parts in the absence of the requirement for assembly could have a significant impact on the future of FEAM. Electronic components are now a reality because of monolithic fabrication. It is not just electrical components that can profit from monolithic fabrication; mechanical components can also be considered, leading to cost reduction and enhancing dependability and quality [35–37].

Materials such as nickel, copper, aluminum, silver, gold and silver-plated solder, and conductive composites are incorporated into a framework or device that is built section by section in a 3D printer by the FEAM method. The process is a one-step way of building up a structure or device layer by layer in 3D printing. On the one hand, it allows for the simultaneous deposition of metal and polymerization; on the other hand, it allows for the simultaneous deposition of metal and/or ferromagnetic wire. FEAM can do both. When it comes to designing robotic constructions with integrated electromechanical components, the capability to

precisely place these three materials (and possibly others) opens up a world of possibilities [38,39]. Additive manufacture of 3D objects using conductive polymers, composites, polymers, and wires is described as a nonlinear and non-3D printing system and apparatus. There is a wide range of applications for these manufactured items, which include robotics, missile batteries, medical equipment, electronic goods, and various other businesses. They are reasonably versatile in that they include circuits, motors, and detectors. FEAM can be used to make devices that include sensors, antennas, integrated circuits that provide computing and storage, and also cells or energy recovery components (e.g., mechanical, electrostatic, capacitance, thermodynamic). In some cases, these sensors could be able to investigate their consumption record and structural rigidity, alerting users to the need for maintenance and providing other condition-monitoring data. IoT-enabled devices are conceivable, as shown in Figures 1 and 2 [40–42].

2.2 Fluid-based AM technique

Wire, fiber, or fluid conduit is partially enclosed within the matrix material in an extruded product that forms at least

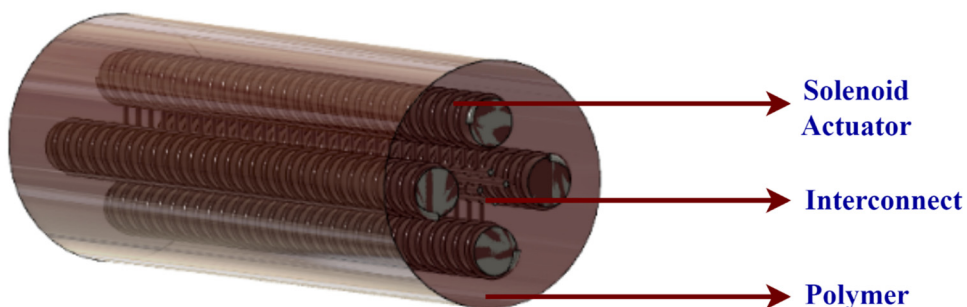


Figure 2: Schematic representation of an isometric cross-sectional view of an FEAM printing head [42].

part of a layer. Although the extrudate's longitudinal axis may be parallel to the primary (*i.e.*, longitudinal) plane of the fiber in certain cases, the fiber could be arranged in any orientation relative to the extruded product in other cases. If the extrudate allows it, the fibers could be twisted or arranged in numerous ways. The dielectric matrix and a long-axis metal cable are approximately similar to the die-extruded materials. A fiber and a matrix material are deposited together, resulting in a fiber wrapped in a matrix. In some embodiments, a fiber enclosed in a grid and comprising at least a part of a layer is coupled to other fibers in the same or a different layer wirelessly, hydraulically, or both. A conductive matrix encapsulates a metallic wire and connects it to additional metal cables in an identical or a separate level. At a minimum, a part of a layer is made up of metallic filaments that are electronically linked to each other through the conductivity matrix, which is made up of polymer and nanoparticles of conductive material. An electrically conductive polymer matrix contains semiconducting particles at a sufficient density to ensure that pollutants from the piezoelectric medium do not significantly reduce conductance, and the accumulation of piezoelectric medium by particulate reinforcement does not impair conductivity [43–45].

Various methods such as joining, melting, annealing, ultrasound or thermosonic gluing, squeezing, wrapping, force connection, and reciprocal tangling are used to attach metal prongs. As long as the matrix phase has not yet solidified, the primary axis of the fiber is largely parallel to the extrudate's axis, which allows for the monolithic fabrication of actuators, sensors, and wires while still contained in an originally liquid matrix material. Using a layer-over-layer AM method that incorporates multi-material, multifunctional layer-by-layer 3D circuitry that includes controllers, detectors, temperature control components, valves, converters, explosives, semiconductors, capacitance, inductive loads, and transmitters can be created. An enclosed metallic wire is soft and tempered in some circumstances, while in others, it has a circular broad spectrum [46,47]. The structure of an insulated metallic wire can be square based on the implementation. A spindle or other fiber storage device is rotated to offset the torsion caused by the deposition of a matrix and a fiber along a curved path. Co-deposition of a matrix and fiber over a curved path is performed regularly and radially to prevent twisting induced by the formation. For filament dispensing, the deposition head includes at least a single stream path for the metal matrix and at least one pipette. Variations in dielectric and conductive substances can both be included in the lamination necks at a minimum single flow path [48,49].

If moving through the fluid flow in any way, the micro-vascular in the deposition tip will dislodge and expel water from the fluid flow entirely. For instance, a deposition head may have a clamp that secures filament in place, and the capillary it is attached to is used to trigger the clamp. Vibration is being used to dispense or feed thread from a lamination device. Anchoring the filament in cemented matrix material, and afterwards pulling it off the deposition head, is the technique being used to feed variations strands [50,51]. Deposition heads use two or more rollers that touch the thread and move it *via* a capillary considerably larger in size than the filament's exterior size to distribute or supply filaments. To put it simply, mechanical fatigue causes the filaments of variation to become brittle and break. It is necessary to eliminate matrix material from the filament when it exits a funnel or other wrapping so that it does not get encrusted with metal matrix. Laser treatment, burning, manual peeling, and plasma etching are used to remove the matrix material from a filament. Vascular height and/or filament feed rate are used to regulate fiber orientation within the extruded product all along deposition (*e.g.*, vertical) axis. In some representations, fiber stance is governed in a closed-loop manner by sensing the filament position inside the extrudate and adjusting accordingly [52,53].

Capillary rotational angle and/or printer speed can be used to control filament position within a bent extruded product inside the layer planes (*e.g.*, horizontal). Paths that comprise enclosed filament are preferred over those that do not contain filament and are ranked less. Pick-and-place or other techniques are being used to incorporate discrete parts into the completed item during the fabrication method. To maintain at least a few of the solid supports in the final product, gadget, element, system, product, or assembly, a detachable and advantageously soluble support material is provided, and at least some of the solid support is substantially contained in the matrix material. Some heat flux constructions use polypropylene and conductive particles as part of their conductive matrix to create integrated elements such as resistors with variable resistance, force sensors, temperature sensors, armatures, and cores for electromagnetic devices and capacitor plates for heating elements. Every one of these elements contains voids filled with fluid and may even be interlinked in many variants [54–56].

Gentle robots are an important application of some of the disclosures. It is common for traditional robotic systems to be made up of rigid components with rotating joints and limited actuators that can only move in one direction. Several technological and operational demands are enabling the growth of novel soft robotic systems. Soft

robots may be better suited than hard ones to operate safely and productively with and in close vicinity to people because of their inherent compliance. Rigid robots have found it difficult to reliably grab and manipulate fragile, flexible, and irregular things (such as tools or apples on a tree) without damaging them; soft robots, on the other hand, provide an extra organic and possibly simpler response. It is possible that a soft robot, rather than a rigid one, could be used for rescue operation or soldier assistance because of its ability to crawl through small spaces [57,58]. The pulsatile movement of a caterpillar is one example of biomimetic locomotion that soft robots can use to navigate narrow passageways and uneven terrain. Soft robots can be more resilient, lighter, cheaper, and louder to handle than tough ones. It is also possible to incorporate high-resolution visual/tactile sensors into the skin of a soft robot, such as the GelSight substance, that has microscopic particles incorporated into its surface (GelSight Incorporation, Waltham, MA) [59,60].

Soft robots have a high number of variables, and many actuators can be impracticable, expensive, and bulky to construct and integrate using discrete parts of broad-area touch sensing. This is a major challenge for soft robots. Robotic limbs and bodies will need to have “embedded sensors and devices in natural fibers for robot bodies” over the next decade. The disclosure of a previously unheard-of capacity to print robots on their own enables automated, custom, quick, low-cost manufacture of whole, working robotics and robots’ components, including application-specific robots. When integrated circuits, memory, optoelectronic components, and radio frequency identification components are included in robotics systems in the form of micro-electromechanical system components, they can provide even more capability [61,62]. Other fields of application include strongly proficient, lifelike prosthetics; minimally invasive surgical instruments, microchannel gadgets with constructed pumps, high-temperature components mixers, and filters, which may incorporate fibers, optical fiber spacecraft, and electrode materials (*i.e.*, for polyacrylamide gel); tailoring portable and bendable gadgets with integrated sensing devices and communication; and microchannel gadgets with constructed impellers and heaters. According to the description of the invention of this study, an innovative packaging approach can free electronic goods from the rigorous, horizontal restriction of printed circuits and offer new 3D screen sizes in which the item and loop become one. This approach removes various layers of traditional packaging, reducing size, weight, and cost while increasing the reliability of these product lines. Other fibrous elements, including fluid conduits and optical fibers, can be included in polymer structures manufactured according to the discovery [63,64]. All the above discussion underscores the importance of integrating

IoT for the manufacturing of composite materials in various applications. Besides, the use of IoT has extended to the quality assessment of manufactured composite materials, which is comprehensively discussed in the forthcoming section.

3 Quality assessment for polymer composites using IoT

This article is related to the polymer composite materials manufacturing systems, methods, and apparatuses, specifically addressing automated quality checks for manufactured composite materials. A primary aspect involves an automated inspection system for monitoring a manufacturing process. This system comprises a core platform to connect various systems or subsystems *via* one or more interfaces and a sensor system coupled with the core platform to monitor the characteristics of a composite article being manufactured. The core platform is configured to receive a first measurement of one or more characteristics of a composite article from the sensor system while forming the composite article, receive data regarding a second measurement of one or more characteristics from the sensor system after curing the composite article, and generate an alert in response to detection of a defect in the composite article based on the first or second measurement [65,66].

The system further comprises a state manager operatively coupled with the core platform to determine a defect associated with one or more characteristics. The state manager is configured to determine whether a first defect exists in the composite article based on the first measurement. It is also configured to determine whether a second defect exists in the composite article based on the second measurement. Additionally, it is configured to identify a value corresponding to one or more characteristics associated with the defect based on the first or second measurement and calculate a score representing the degree of the defect of the manufactured article based on the identified value. The core platform is further configured to receive data regarding a third measurement of one or more characteristics after performing a trim operation on the composite article, determine whether a third defect exists in the composite article based on the third measurement, and generate an alert in response to a determination that a third defect exists in the composite article. The system further comprises a human-machine interface (HMI) operatively coupled with the core platform to provide an interface between an operator and the system. The core platform is

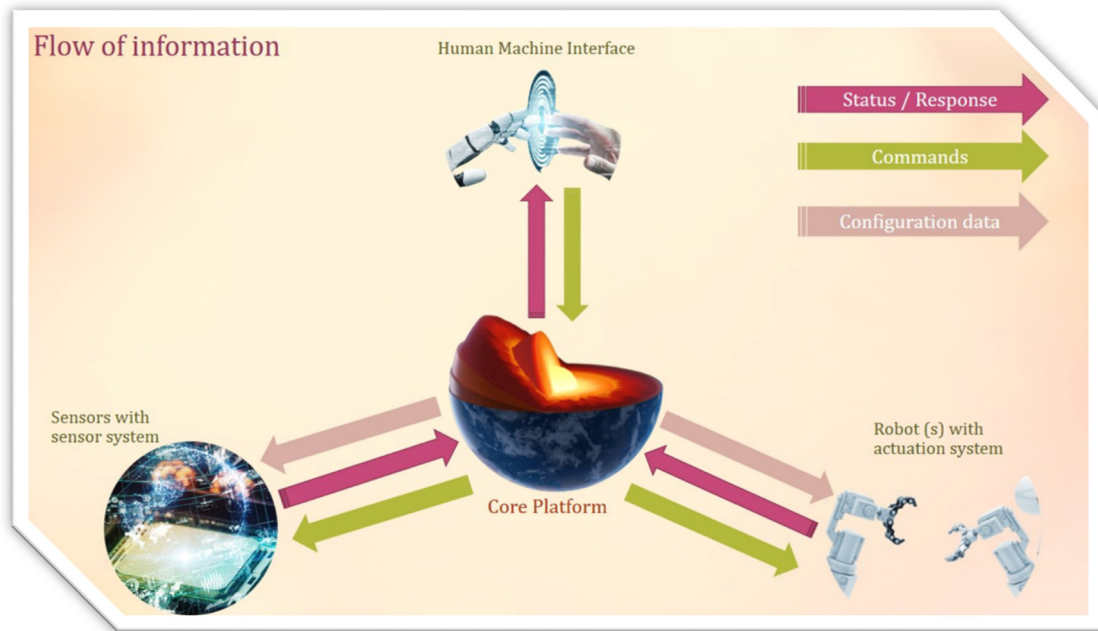


Figure 3: Schematic representation of flow of information data between subsystems. Adapted by a permission from [85].

configured to transmit the alert to the HMI, the alert comprising one of an audible or visual alert [67–69].

The system further comprises an actuation system operatively coupled with the core platform to implement

the manufacturing process based on instruction from the core platform, wherein the core platform transmits the alert and information regarding the first or second defect to the actuation system to adjust an operating value of a

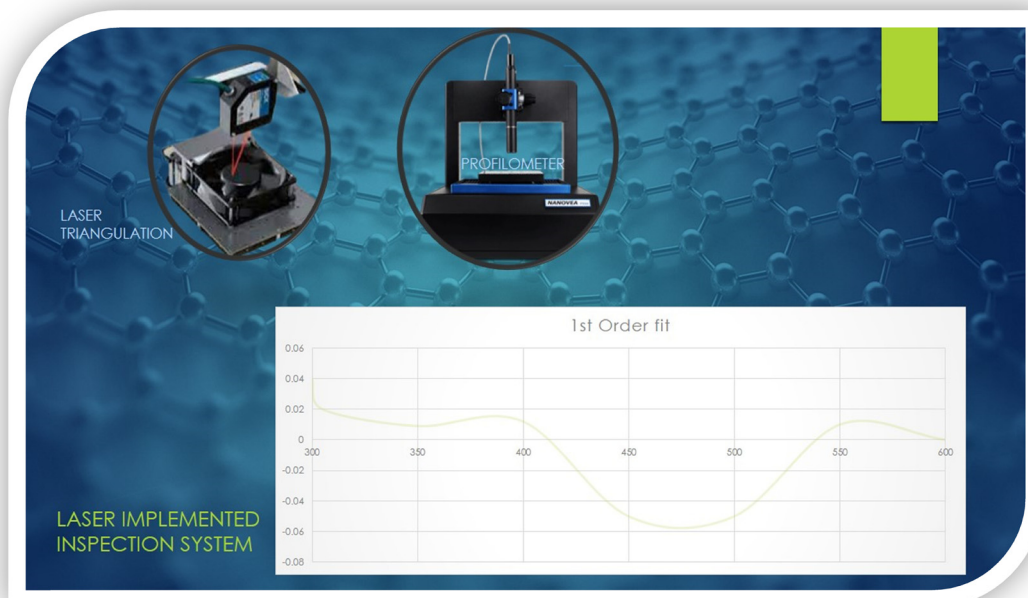


Figure 4: Schematic representation of an example layup process and elements of a laser-implemented inspection system. Adapted with a permission from [85].

Table 1: IoT versus polymer composite material

S. No	Description	Purpose	Ref.
1	Perovskite material	Enabling IoT	[86]
2	Carbon nano-tubes	Enabling IoT	[87]
3	Reinforced composite	Manufacturing	[88]
4	Composite software	Reduce the manufacturing cycle	[89]
5	Adaptive apps and platforms	Produce as well as to certify	[90]
6	Sensors in the testing zone	Image capturing, transfer	[91]
7	Optimization in production	Manufacturing and patent protection	[92]
8	Production	Reduces cost, waste, and downtime	[93]
9	Electronic components	Enabling IoT	[94]
10	Through sensor	Information transfer	[95]
11	Diagnosis autonomously	Health monitoring	[96]
12	Real-time diagnosis	Uncertainty assessment	[97]
13	UAV blades	Composite layups	[98]
14	Patterning for conductivity	Enabling IoT	[99]
15	Manufacturing	Load prediction	[100]
16	NDT	Defects assessment	[101]
17	Manufacturing	Improve the reliability	[101]
18	Proper transmission of current	Enabling IoT	[102]
19	Production	Mechanism saving	[103]
20	Efficiency in conversion	Bending strength analysis	[104]
21	Production	Realization	[105]
22	Smartphone	Monitoring the motion	[106]
23	Manufacturing	Integrating devices smoothly	[107]
24	Aircraft vibration	Power harvesting for sensors	[108]
25	Assessing conductive polymers	Enhance production	[109]
26	Smart manufacturing	Info sharing	[110]
27	Two-phase material	Develop dynamic sensor	[111]
28	Manufacturing	Trainer kit designing	[112]
29	Production	Enhancing the process	[113]
30	Cellulose nano-fibril	Enhance the conductivity	[114]
31	Image processing with sensor	Assessing state of drying	[115]
32	Production	Quality assessment	[116]
33	Improve the sensor	Estimate dynamic data	[117]
34	Supermolecular polymers	Modulating network percolation	[118]
35	Composite physical chemistry	Teaching the experiments	[119]
36	Failure data analysis	Leverage NDT data	[120]
37	Halide Perovskite nano-generator	Real-time data gathering	[121]
38	Coconut shell helmet	Strength analysis	[122]
39	Manufacturing	Process assessment	[123]
40	Nano-fibers	Pressure sensor	[124]
41	Cellulose nano-fiber	Data analysis	[125]

Table 1: Continued

S. No	Description	Purpose	Ref.
42	Flexible antenna	Reconfigurable	[126]

manufacturing process of the system. The operating value comprises the speeds of the manufacturing process, the temperature of the curing stage, and the position of the composite article. The sensor system is operatively coupled with one or more of a noncontact ultrasound sensor, a laser sensor, an impedance sensor, an infrared sensor, or a heat sensor. The sensor system monitors one or more characteristics by two or more sensors of the sensor system to determine the first or second defect in the composite material. In certain aspects, the characteristic comprises a density, temperature, chemical composition, and thickness associated with the composite article [70–72].

A method of determining the integrity of a composite article comprises measuring, by a sensor, a first characteristic corresponding to the integrity of a composite article while forming the composite article; measuring, by the sensor, a second characteristic corresponding to the integrity of the composite article after curing the composite article; identifying, at a core platform, a defect based on the characteristic; and generating an alert in response to a determination that a defect exists in the composite article based on the first or second characteristic. The method further comprises determining, by the core platform, a defect value associated with the first or second characteristic, comparing the defect value to a plurality of defect values, and designating the manufactured article as containing a defect based on the comparison [73,74]. Besides, identifying by the core platform, a stage at which the defect appears; and adjusting an operating value of a manufacturing process based on the identification. The operating value comprises the speed of the manufacturing process, the temperature of the curing stage, and the position of the composite article. The density, temperature, chemical composition, and thickness associated with the composite article are also measured. Additionally, the alert is transmitted to an HMI operatively coupled with the core platform. The alert comprises video or audio identifying the defect [75,76].

With the advent of the IoT, whereby computing devices are embedded into everyday objects, the capability of sensing, processing, and communicating task-to-task details has become ubiquitous. To ensure continuous improvement in lean manufacturing, development should focus on issues of data analytics. For example, a computing architecture and

Table 2: Barriers to adopting composites [127]

S. No.	Constraints	Description
1	Cost	Finances involved in research and development as well as equipment cost to manufacture and testing is high
2	Capability	Need to provide training for the task force, in turn which demands expertise and proper resources
3	Materials data	Discrepancies in the standard define data for the materials are unavailable
4	Intellectual property	IP owned by many stakeholders for smaller portions wherein it requires integration, therein I can be achieved only by collaboration
5	Material systems	While migrating from one material to other new material involves lot of changes in the existing system, which in turn involves huge cost

infrastructure capable of communicating with a plurality of information sources (*e.g.*, sensors, databases, interfaces, *etc.*) and/or analyzing data (*e.g.*, firmware, hardware, software, algorithms, *etc.*) is desirable, such that all data can be compiled into a centralized server and/or data storage [77–79]. Further, given the proliferation of cheap, accurate sensors, the amount of data to parse to obtain meaningful information requires thoughtful consideration. Therefore, there is great potential to use sensors to obtain data from a variety of processes; however, significant hurdles remain before a complete solution is achieved [80,81].

Computing architecture and infrastructure capable of parsing large amounts of data to obtain meaningful information in the context of a variety of systems, for example, the state of an aircraft, the actions of a pilot within that state, and others, has been researched and developed over the years. Hardware and software architecture have been developed to benefit manufacturing technologies. As an example, a system can be configured to use cameras, a core computer containing core operating principles, and an HMI (*e.g.*, a tablet or other computing device) to accept commands and/or share information with an operator [82,83]. In this manner, data can be digitized, such that the manufacturing process checklist can be configured to check for defects (*e.g.*, FOD) on composite manufactured articles. It is further considered that the principles and/or systems described herein will have wide applicability for data capture and analytics to perform continuous improvement, leading to increasing automation. Ultimately, the

necessity of a manual inspection by a Level 3 NDT technician may be eliminated through the methods and systems described herein, as shown in Figures 3 and 4 [84,85].

Table 1 consolidates how IoT is used in the manufacturing of composite materials along with the way it enhances the manufacturing process. In other way, the composite materials are being used in the sensors, which increase the efficiency of the IoT process. It helps the stakeholders to choose the specific type of requirement for a particular composite manufacturing process. Along with that, specific applications can also be identified, which would make it easy for researchers to work with versatile purposes.

4 Challenges and future scope

Implementation of IoT in full-scale for the manufacturing of polymer composites and quality assessment depends on various factors such as the cost of the process including raw materials and systems, the capability of the manufacturing and testing system to be digitized, availability of the data regarding the composition of the raw materials, and the data regarding the materials and manufacturing systems. Some predominant reasons of composite materials are unable to be adopted in product development are highlighted in Table 2.

The scope of polymer composites is always a tailor-made option owing to its pros and cons. A clear direction

Table 3: Scope of IoT in polymer composite manufacturing [128]

S. No.	Capabilities	Description
1	Design and analysis	The advanced technologies enable to test the materials with various digital techniques, leading to enhance the capabilities of composite manufacturing
2	Processes	The growth in digital equipment provides a path to enhance the process like automation in composite manufacturing
3	Materials science	Technological growth paves a path to the synthesis of hybrid materials
4	Technology enablers	Digital world opens a forum to thought about the unconventional manufacturing of weird materials

is important to overcome the constraints it possesses. Table 3 reveals how the barriers can be broken.

5 Summary and conclusions

The survey reveals that composite manufacturing can be enhanced by the IoT in terms of quality and optimization of the raw materials. The primary sectors that use the IoT in composite manufacturing are communication, aerospace, and testing of polymer composites. In the early stage of adaptation of IoT in polymer composite manufacturing, its implementation is very limited. It is believed by experts that continuous progress in the field of IoT-interfaced polymer composite manufacturing requires a few more factors revealing the durability of the composite materials in various environmental factors such as the washing of fibers, high-temperature behavior, and flexural characteristics. There is a need for exploration of new production methods for polymer composite material to enhance the curing process efficiency, thereby improving the efficiency of the polymer composite manufacturing process. As a result, it has a wider scope to grow in the automation of composite manufacturing. It has been revealed that the barriers mentioned in adopting composite materials completely depend on advanced technological growth. Therefore, the incorporation of IoT is crucial for the development of better future composite products, as it can address the above-mentioned constraints. Materialists, technologists, and researchers in the field of composite materials for diverse applications can consider the utilization and full-scale implementation of IoT techniques for composite manufacturing to produce better-quality composite materials.

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