

Construction of sports hall flooring with excellent properties by nanocomposites

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(Received July 15, 2023, Revised November 23, 2023, Accepted November 27, 2023)

Abstract. The rapid evolution of intelligent sports equipment and gadgets has led to the transformation of smartphones into personalized coaching devices. This transformative role is central in today's technologically advanced landscape, addressing the needs of individuals with contemporary lifestyles. The development of intelligent sports gadgets is geared towards elevating overall quality of life by facilitating sports activities, workouts, and promoting health preservation. This categorization yields two primary types of devices: smart sports devices for exercise and smart health control devices, which encompass functionalities such as blood pressure monitoring and muscle volume measurement. Illustrative examples include smart headbands, smart socks, smart wristbands, and smart shoe soles. Significantly, the global market for smart sports devices has garnered substantial popularity among enthusiasts. Moreover, the integration of sensors within these devices has instigated a revolution in group and professional sports, facilitating the calculation of impact intensity and ball speed. The utilization of various types of smart sports equipment has proliferated, encompassing applications in both sports' performance and health monitoring across diverse demographics. This article conducts an assessment of the application of nanotechnology in the continuous modeling of the magnetic electromechanical sensor integrated within smart shoe soles, with a specific emphasis on its implementation in soccer training. The exploration delves into the nuanced intersection of nanotechnology and sports equipment, elucidating the intricate mechanisms that underlie the transformative impact of these advancements.

Keywords: health monitoring gadgets; intelligent sports equipment; nanotechnology in sports; soccer training technology; smart sports devices

1. Introduction

In the past thirty years, significant advancements have been made in the field of microelectronics, enabling the implementation of complex electronic circuits on small surfaces and the fabrication of micron-scale sensors (Shishesaz *et al.* 2018). The inception of micro-electro-mechanical systems (MEMS) technology can be traced back to 1964 when the first composite part incorporating MEMS was developed. During the 1980s, extensive laboratory research on MEMS gained momentum, leading to the mass production of these systems as components in the mid-1990s (Chadha *et al.* 2023). The utilization of integrated circuits (ICs) and components such as Bipolar and complementary metal-oxide-semiconductor (CMOS) has greatly benefited electronics manufacturers (Topol *et al.* 2006). Concurrently, the integration of micro-mechanical parts and micromachining processes onto different layers of silicon semiconductors resulted in the convergence of these two industries, giving rise to the birth of "MEMS" technology (Wang *et al.* 2022, Jia *et al.* 2023, Zhang *et al.* 2023a, c, d). This technology facilitated the realization of complete chip systems through its implementation (Skrzypacz *et al.* 2022). Smart manufacturing advances through the understanding and control of microsensors and

microactuators and the power of microelectronics. MEMS is a highly capable technology (Ehyaei *et al.* 2017, Ghadiri *et al.* 2017a, b, Shivanian *et al.* 2017). Additionally, MEMS is a very versatile technology, both in terms of its use and in terms of how it is used to make and design tools. Integrated microelectronic circuits (IC) are systems' brains, and MEMS extends this thinking power by adding eyes and arms so that these microsystems can sense and control their surroundings (Abdehvand *et al.* 2021). By measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena, sensors collect data from the environment (Alsultan Abdulmajeed 2021, Dai *et al.* 2021, Alimoradlu and Zamani 2022, Behdinin and Moradi-Dastjerdi 2022, Thakur *et al.* 2022, Zhao *et al.* 2022). Electromechanical systems take input from sensors and, using their decision-making capability, instruct actuators to react, such as moving, shifting, regulating, pumping, filtering, and guiding the environment to accomplish desired results (Anjum and He 2020). In MEMS devices, similar to ICs, a very high level of functionality, reliability, and complexity can be built on a small silicon chip at a very low cost due to discontinuous manufacturing techniques, which are located on a layer of strategic silicon material. Based on electronic chip technology, this structure is very small in dimensions in the micron range (Di Barba *et al.* 2020). Today, in the advanced countries of the world, the development of mechanical and electronic systems in very small dimensions is of interest because these important scientific parts will increase the speed and reduce the size of industries in a wide range of industrial and general

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applications (Andrzej 1999). Among the most influential industries of the world, including automotive, chips, and sports equipment manufacturing, micro-electromechanical systems technology is widely used (Mollaee *et al.* 2023a, Mollaee *et al.* 2023b, Ramezani Azqandi *et al.* 2023). It has become necessary for many countries today to develop this technology, produce products, and invest in it (Žur *et al.* 2020). Methods of group production are used. The advantages of MEMS as a manufacturing technology are numerous. In MEMS, group manufacturing technology leads to increased efficiency and reliability, reducing size, weight, and price. Also, MEMS is the basis for the production of products that cannot be produced in other ways (Zhu *et al.* 2023). Along with the advantages of MEMS, there are many technical obstacles and problems on the path of miniaturization that need to be overcome. ICs use the electrical properties of silicon, while MEMS also use the mechanical properties and other advantages of silicon (Mirjavadi *et al.* 2020a, b, c, Afshari *et al.* 2022). Other advantages include the following (Will-Cole *et al.* 2022): The type of MEMS technology and its variety of useful applications make it potentially a more ubiquitous technology than even IC microchips. MEMS eliminates the distinction between complex mechanical systems and electrical IC circuits. Sensors and actuators are the most expensive and unreliable parts of a large-scale electronic system (Daihyun *et al.* 2005). MEMS technology allows these complex electronic systems to be manufactured for use in integrated manufacturing techniques. This action has made the reliability of sensors and actuators acceptable to the level equal to the accuracy of ICs (Rahman and Reif 2001). In these systems, the microsensor detects changes in the environment around the system by measuring mechanical, thermal, magnetic, chemical or electromagnetic phenomena and information (Arefi and Zenkour 2017). The microelectronic part processes this information and sends a control signal to the operator to make the necessary changes. MEMS can be used in the automotive, electronics, communication, and printing industries (Ho and Tai 1998). Existing MEMS components include car airbag accelerometers, inkjet head printers, blood pressure sensors, optical micro-switches, biological sensors, and smart sportswear (Saadon and Sidek 2011). Considering the wide range of the number of people engaged in sports activities and the professionalization of this industry, which has caused billions of dollars to be invested in it, any tool that can somehow improve the performance of athletes is the attention of investors and sports practitioners will take (Gubbi *et al.* 2013). Today's consumers need sports equipment that stays clean, smells good, is comfortable, easy to care for, and looks great. Of course, it should be noted that improving the athlete's performance is the first priority (Hu *et al.* 2023, Miao *et al.* 2023, Zhang *et al.* 2023b). In the meantime, nanotechnology in the sports industry has attracted a lot of attention (Kos and Umek 2018). Sports equipment and products modified with nanotechnology are used for a wide range of activities, such as ballooning, parachuting, snowboarding, aerobics, cycling, athletics, hockey, climbing, swimming, sailing, sailing, skiing, and soccer (Kunze *et al.* 2017). Considering

the challenging conditions of these sports, the use of sports clothes and equipment with multi-purpose features is particularly important (Baca *et al.* 2009). For example, advanced materials used in flexible and stretchable electronic equipment can improve the performance of athletes (Yang *et al.* 2022, Cai *et al.* 2023). Textile industry manufacturers have produced smart fabrics that have sensors or portable charging devices and are mainly used to obtain biological information (such as heart rate, body temperature, etc.) (Michahelles and Schiele 2005). Obviously, the above-mentioned sportswear should have at least basic features, such as comfort, safety, conventional stretch capabilities, lightweight, and dimensional stability (Yu *et al.* 2016). Smart sports are part of the emerging phenomenon of the Internet of Things (IoT), in which objects are connected to the network through the Internet, collect and share information. With the help of this advanced technology, information is collected and used to measure sports performance (Xiao *et al.* 2023). Therefore, the concept of smart sports gives users an opportunity to record and track their information. Sports equipment and devices collect information and transfer it to mobile phone applications or cloud systems. These programs have the ability to analyze data and can even create a kind of "virtual coach" through them (Laghari *et al.* 2022). The important thing about sports equipment is the need to have features such as compressibility, waterproofness, health monitoring, and breathability. Usually, for the design and manufacture of such equipment, chemicals such as phthalates, dimethyl formaldehyde (DMF), and similar substances are used, which can have harmful side effects. In addition, the above compounds lose their special properties after several items of washing (Marjani *et al.* 2017). Therefore, in recent years, researchers have focused on this issue to produce sports equipment that retains its properties and, at the same time, does not pose a risk (Azimi *et al.* 2016, Ghadiri *et al.* 2016a, b, Shafiei *et al.* 2016, 2017). The use of nanotechnology creates the most durable sports equipment that not only does not have side effects but also will not affect the comfort and softness of the fabric (Umek *et al.* 2015). Today, using this technology, sports equipment with unique properties are produced, including waterproof, antibacterial, UV protection, self-cleaning, insulation, increased blood circulation, muscle improvement, and electronic properties (Lee and Lee 2015). Several active companies in the textile field have commercially used nanotechnology in their sportswear. "Scholler" is a Swiss company active in the field of manufacturing and producing sports equipment that has used nanotechnology to produce clothes with light balance, air permeability, water and wind resistance, and self-cleaning (Chen *et al.* 2023). These clothes are mostly used in sports such as climbing and skiing that are performed in cold weather. It should be noted that Adidas, as one of the largest active companies in the field of sportswear production and supply, has produced a set of sportswear, including t-shirts, sports shorts, and shoes, using smart fabrics (Crowell *et al.* 2010). It helps to reduce the athlete's body temperature during exercise, and the signals received by the clothing are sent to the user's mobile applications to evaluate and implement effective strategies.

Smart textiles are generally textiles or products that recognize changes in the user's local environment and respond appropriately (Casamassima *et al.* 2014). For example, a lightweight nanomaterial-based wearable system keeps the body comfortable in an outdoor environment with temperatures ranging from -50 to +50 degrees Celsius (Umek *et al.* 2017). Materials commonly used in the production of smart textiles include phase change materials (PCMs), shape memory materials (SMMs), chromic (color changing) materials, conductive materials, and textiles integrated with MEMS electronics. It should be noted that the use of smart materials and nanotechnology in sports equipment has many applications, including communication between devices, transfer of heat or electricity, improvement of the user's sense of clothing, and reaction and protection against environmental hazards (Ray 2015). According to their function, these sports equipment are divided into three categories:

1- Passive smart sports equipment that only senses environmental conditions or stimuli (Ebrahimi *et al.* 2017, Ghadiri *et al.* 2017c, Shahabinejad *et al.* 2018, Shafiei *et al.* 2020).

2- Smart sports equipment that has both sensors and activators (Omidi *et al.* 2013, Ghadiri *et al.* 2016c, Mousavi *et al.* 2017). Activators are activated directly or controlled by a central unit. Examples of active smart sports equipment are water-resistant and vapor permeable (hydrophobic/non-porous), heat storage, heat regulating, vapor absorbing, heat wicking, and electrically heated fabrics.

3- Super smart sports equipment that can sense, react, and adapt itself to environmental conditions or stimuli (Smart 2007). A super-intelligent sports equipment consists of a unit that acts like a brain and has the ability to understand, reason, and act. Sports equipment that has electronic features can be used to collect vital information, and obviously, one of the innovations related to sportswear will be the case (Tjønndal and Nilssen 2019).

These fabrics play a role in the health care and protection of athletes in sports such as football, and their main purpose is to record physiological and biological changes in the body and record vital signs. In better words, electronic textiles are infrastructures that have the ability to sense (environmental biometry), communicate (usually wireless), and transmit power so that sensors and information processing devices, in an integrated manner, form a unique network (Pierleoni *et al.* 2022). These fabrics generally have conductive yarns that are twisted or twisted with some conductive material (such as silver or stainless-steel filaments) to allow electrical conduction. Intrinsically conductive resins are a new and very important group of resins that have been of great interest due to their high application potential in various industries, such as electronic sensors and anti-corrosion coatings (Umek *et al.* 2016). Among these resins, polyaniline has received great attention among conductive polymers due to its unique characteristics, such as good stability against oxygen, high electrical conductivity, cheapness, and easy synthesis (Geniès *et al.* 1990). Polyaniline is one of the best and most widely used polymers. It is among conductive polymers (Syed and Dinesan 1991). Considering that polyaniline has

the ability to produce one-dimensional structures such as nanotubes, nanowires, colloidal nanoparticles, and nanofibers, a lot of research has been done about it (Boeva and Sergeyev 2014). The method of producing shoe soles using smart polyaniline conductive resins, which facilitate more effective performance in daily sports activities, is the subject of this article. Running in cold weather, particularly during long-term football training sessions, can be challenging (Yang and Zhang 2022, Zou *et al.* 2023). However, the utilization of smart shoe insoles incorporating nanotechnology provides a convenient solution for exercising and running in such conditions (Cao *et al.* 2022, Cheng *et al.* 2024, Liu *et al.* 2024). These smart shoe soles are specifically designed to keep feet warm during cold weather activities, particularly running. One notable feature of these smart shoe insoles is the ability to adjust the insole temperature according to the user's preference. The maximum heat generated by these smart insoles is approximately 115 degrees Fahrenheit. The temperature adjustment of these insoles can be conveniently done through their dedicated mobile application. Furthermore, these smart insoles offer the additional functionality of tracking step count, distance traveled, and calorie expenditure during physical activities (Zhang *et al.* 2022, Xue *et al.* 2023, Zhao *et al.* 2024). Additionally, beyond providing warmth in cold weather, this smart device can generate heat for the feet during daily activities and sports, aiding in the reduction of heel pain and facilitating energy recovery.

While the rapid development of intelligent sports equipment and gadgets has revolutionized the way individuals engage in sports and maintain their health, there are certain shortcomings that need to be addressed (Alsultan Abdulmajeed 2021, Dai *et al.* 2021, Alimoradlu and Zamani 2022, Behdinan and Moradi-Dastjerdi 2022, Thakur *et al.* 2022, Zhao *et al.* 2022). Firstly, the integration of nanotechnology in sports equipment is still in its early stages, with limited research exploring its full potential. This presents an opportunity for further investigation and development (Alimoradzadeh and Akbas 2022, Bochkareva Sergey and Lekomtsev Sergey 2022, Du *et al.* 2022, Gao *et al.* 2022). Secondly, the practical implementation of smart sports devices and nanotechnology in real-world scenarios requires overcoming technical challenges, such as ensuring durability, reliability, and user-friendliness (Dan *et al.* 2015, Turkeli *et al.* 2017, Zhai *et al.* 2018, Shakouri *et al.* 2021, Mekki *et al.* 2022, Oumedour and Lazzali 2022). Bridging the gap between laboratory research and commercial applications is crucial to enable widespread adoption of these technologies (Medani *et al.* 2019, Ramteke Prashik *et al.* 2019, Bamdad *et al.* 2020, Jia *et al.* 2020, Mirjavadi Seyed *et al.* 2020, Zhou *et al.* 2020).

The novelty of this study resides in the exploration of nanotechnology's application in the continuous modeling of magnetic electromechanical sensors integrated within smart shoe soles designed for soccer training. This research advances the current understanding by delving into the utilization of a polyaniline-nano iron oxide-silver nanocomposite, synthesized through the solution casting method. The investigation rigorously evaluates the electrical, mechanical, and thermal stability properties of

this nanocomposite, aiming to discern its potential impact on sports performance. The integration of nanotechnology into sports equipment introduces a unique paradigm, offering a novel avenue to enhance the comfort, performance, and health monitoring capabilities of athletes. Bridging the gap between nanotechnology and sports equipment holds significant promise. The infusion of nanocomposites into sports gear has the potential to augment durability, waterproofness, antibacterial properties, UV protection, self-cleaning capabilities, insulation, and blood circulation improvement, thereby affording athletes a competitive advantage. Furthermore, the incorporation of nanotechnology facilitates the development of smart textiles capable of sensing changes in the user's environment and responding accordingly, thereby enhancing comfort, safety, and personalized performance optimization.

By harnessing the potential of nanotechnology in sports equipment, manufacturers can pioneer innovative solutions that align with the escalating demands of athletes for high-performance, multifunctional, and sustainable products. The application of nanotechnology in sports equipment represents a promising avenue for bolstering sports performance, comfort, and health monitoring capabilities. Nonetheless, addressing these promising prospects necessitates further research to surmount technical challenges and bridge the divide between laboratory advancements and practical implementations. By systematically addressing these shortcomings and unlocking the untapped potential of nanotechnology, sports equipment manufacturers can spearhead transformative solutions that revolutionize the sports industry, providing athletes with unparalleled performance and user experiences.

2. Materials, devices and methods

2.1 Materials and devices

Aniline, sodium dodecyl sulfate, hexanoic acid, ammonium persulfate, iron (II) chloride 4, iron (III) chloride 6, and paraffin were all purchased from Merck. AgNO₃ nanoparticles with a size of 40 nm were obtained from Merck. In order to test the absorption of waves, the samples were prepared with two different formats in terms of dimensions, i.e., 150x100 and 10x10x20 mm. The formation of fibers and their shape has been observed with the help of a scanning electron microscope model XL-30A made by Philips, Netherlands. The diameter of the formed fibers has been calculated and reported by measuring 100 different points. The electrical conductivity of the layers prepared from nanofibers in the electrospinning process was determined by the standard four-point method, and after doping, the samples with hydrochloric acid vapor 560 made in the USA have been registered and reported in the area of 2000-1300⁻¹ cm. The thermal analysis device TGA Model 189 Build 3.6V 50Q was used to investigate the thermal stability of polyaniline and its nanocomposites in order to determine the effect of zinc oxide nanoparticles and their amount on strengthening the thermal stability of polyaniline. Mechanical properties were investigated by performing a tensile test using a tensile device. INSTRON

Model 5566, made in America and with a strain rate of 5 mm/min, was done on polymer films six centimeters long, one centimeter wide, and 80 microns average thickness. To determine the conductivity of polyaniline and its nanocomposites, the 4-point method was used. For this purpose, a 4-point probe system was made based on ASTM standard 4496-84, and then the conductivity of the polymer films was measured after being doped by 1.5 M hydrochloric acid solution became. The difference has been determined by using universal thermometer model V3.8B to make a sample of the shape and diameter distribution of nanofibers formed at 25 temperature and American TA instruments at 40 to 200 temperature under nitrogen gas and heating rate 10°C/min. The used electrospinning machine consists of Gamma High Voltage Research high voltage source and a New Era Pump Systems injection pump made in America.

2.2 Synthesis of polyaniline

Polyaniline was synthesized from the chemical oxidation of aniline by ammonium persulfate in an acidic medium. First, freshly distilled aniline (164 mmol) was dissolved in 1.5 M HCl aqueous solution and stirred for one hour to form anilinium chloride ions, and since the polymerization reaction must be performed at a temperature lower than 4°C, the vessel containing the reaction mixture was placed in a water bath. Ice was placed. Next, the amount of 164 mmol of ammonium persulfate in 1.5 M HCl aqueous solution was added dropwise to the mixture containing monomer by burette over 6 hours. With the addition of the first oxidizing drops, the appearance of green-blue color indicates the beginning. After adding all the oxidants to complete the reaction, stirring was continued for another 2 hours. After the reaction mixture was filtered with ethanol and acetone until it became colorless, the solution was washed under a filter, and finally, it was washed with distilled water, and then the resulting solid was dried at room temperature for 24 hours at a temperature of 50-60°C.

2.3 Synthesis of Fe₃O₄ nanoparticles

In a three-month flask, 5.7 grams of iron chloride (III) and 20 grams of iron chloride (II) were dissolved in 450 ml of distilled water under nitrogen gas and vigorous stirring. The openings of the three-hole balloon should be such to prevent oxygen from entering the solution because it causes the oxidation of iron (II) oxide to iron (III) oxide. Then 30 ml of 25% ammonia solution by weight was slowly added to the solution and was subjected to vigorous stirring in a water bath at 60°C for one hour. In the end, the nanoparticles were separated from the solution by a magnet and washed several times with distilled water and ethanol, and then dried.

2.4 Preparation of polyaniline / silver nitrate / iron oxide nanocomposite (III)

0.01 mol of hexanoic acid (1.5 g) with 0.01 mol of aniline monomer (0.95g) was stirred in 20 ml of distilled

water for 30 minutes with a magnetic stirrer, 10 g of AgNO_3 and 10 g of iron oxide (Fe_3O_4) was poured into the solution after removing the magnetic stirrer and placed under ultrasonication for 4 hours. After ultrasonication, 28.2 grams of ammonium persulfate was dissolved in 20 ml of distilled water and added to the solution by burette for 2 hours. At the same time, the resulting solution was stirred and placed at 0°C for 24 hours, and finally, the product was washed three times with distilled water and methanol.

2.5 Methods of preparing samples for absorption measurement

The sample was prepared by two methods to check the absorption of radar waves: a) in the form of a physical mixture, in this method, after grinding different materials in a mortar to make the particles uniform, the samples are mixed, and finally a suspension of the resulting powders is prepared in paraffin. b) In the form of a composite, in this method, the polymerization of aniline is carried out in the presence of a uniform mixture of silver nitrate, iron oxide, and aniline monomer in a state where they are strongly mixed, and the composite has a core-shell structure.

2.6 Preparation of film with paraffin substrate

Paraffin is used to make a mold for quick preliminary tests because it melts easily due to heat, and a suspension can be easily prepared from the test sample, and it solidifies after pouring on the glass.

a) 100 x 150 mm mold: first, 2 grams of the sample mixture is powdered in a mortar, and on the other hand, 20 grams of solid paraffin for a 10% film is turned into a liquid form on a heater at a temperature of 90°C , then the nanocomposite powder becomes. It is added after stirring for 8 minutes at a temperature of 95°C , it is quickly poured on a 100-150 mm glass to be better heated, and the prepared film is used for the absorption test. Films prepared with 10 x 15 cm formats are only suitable for preliminary tests due to the high use of materials and lack of proper uniformity.

b) 10x11x21 mm mold: 10x11x21 mm mold was prepared from rice, and then the sample prepared as a soft powder was mixed with paraffin and heated at 95°C for 8 minutes. And the mixture was poured into the heart in a molten state and removed from the mold after 5 minutes. It should be noted that although paraffin itself is oily, it is better to smear the inner opening of the mold with grease before pouring the material into the mold so that the mold can be removed easily.

3. Results and discussion

3.1 Examining the SEM image of polyaniline-iron oxide nanocomposite

The scanning electron microscope (SEM) method is widely used to determine the shape morphology and estimate the size of particles in micro and nano dimensions. In order to investigate the distribution of iron oxide and silver nanoparticles in polyaniline, the SEM image of

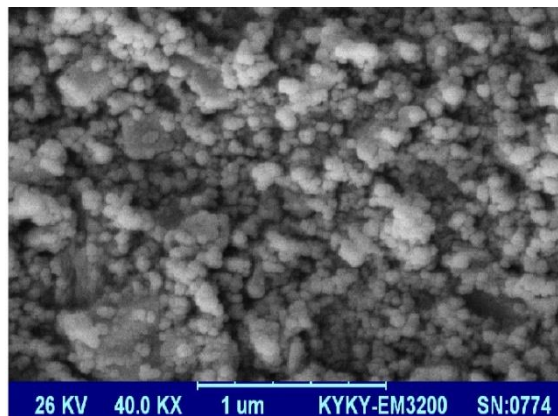


Fig. 1 SEM image of polyaniline-iron oxide nanocomposite

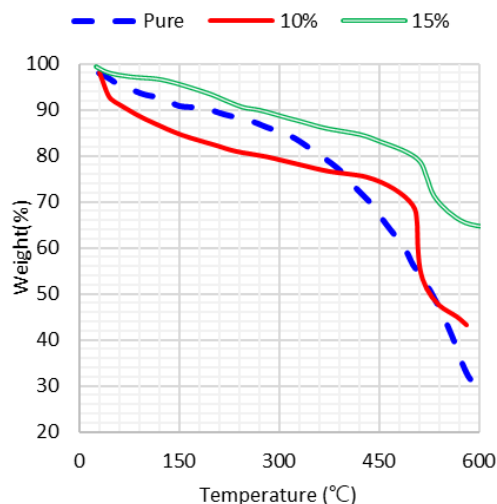


Fig. 2 TGA curve of polyaniline(pure) and its 10 and 15 percent nanocomposites

polyaniline-iron-oxide-silver nanocomposite was prepared at a scale of 200 nm. This image confirms the distribution and non-aggregation of iron oxide-silver nanoparticles in polyaniline, as shown in Fig. 1. The nanoparticles are homogeneously distributed in the field of polyaniline and are not lumpy. The corresponding SEM image shows the formation of magnetic nanoparticles in a cubic ratio on the surface of the nanoparticles. From this image, it can be understood that the nanoparticles have a suitable distribution range. Based on the obtained image, the average particle size for Fe_3O_4 nanoparticles is estimated to be about 45 nm.

3.2 Investigating the thermal stability of polyaniline and polyaniline-iron-silver oxide

Determination of thermal stability of polyaniline and its nanocomposites were analyzed by thermogravimetric analysis (TGA). According to the results of the TGA analysis (according to Fig. 2), three areas of weight loss can be observed. Weight loss at temperatures below 100 is related to the removal of water molecules absorbed by the polymer. The second weight loss is around 2000 and near the boiling point of the solvent used to prepare the film

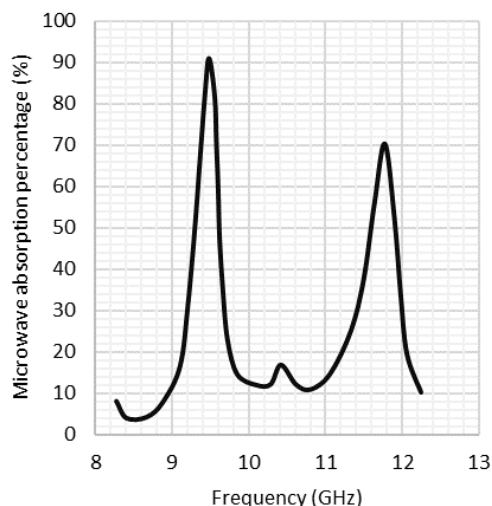


Fig. 3 Curve of microwave absorption percentage by frequency: Mixture of poly/aniline oxide, iron(III)-silver oxide with 15% by weight and 5.5mm thickness

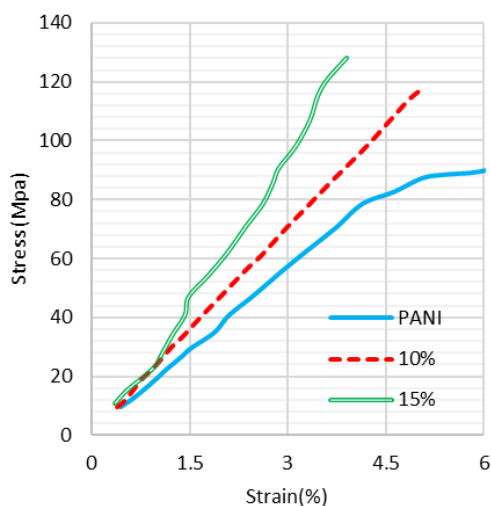


Fig. 4 Curve of stress-strain changes of polyaniline (PANI) and its 10 and 15 percent nanocomposites

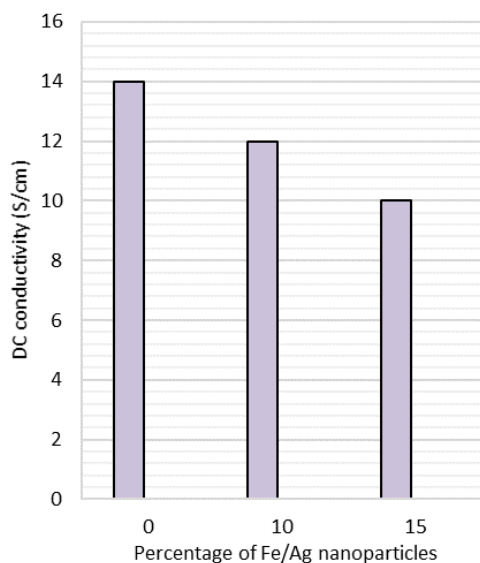


Fig. 5 Changes in the conductivity of polyaniline according to the amount of iron-silver oxide nanoparticles

(NMP). It was observed that the third weight loss was observed at temperatures higher than 390 for pure polymer and at 450, which indicates the destruction of the polymer structure. From the results of TGA, it is clear that the thermal stability of polyaniline increases in the presence of nanoparticles. Also, with the increase in the percentage of nanoparticles, the thermal stability also increased, so that the weight loss of pure polyaniline up to the temperature of 600 is equal to 50.6%, but this value is for polyaniline containing 10 and 15% of nanoparticles. Iron-silver oxide particles reached 56.42 and 64.46%, respectively.

3.3 Investigating the adsorption properties of polyaniline-iron oxide-silver nanocomposite

The absorption characteristics of the paraffin sample were investigated in the 8-12 GHz region. As can be inferred from Fig. 3, the highest absorption is at the frequency of 3.9 GHz, and the highest absorption is 91.7%. Adding silver to the nanocomposite reduces the frequency of absorption and increases the return power loss compared to the case where only iron oxide and aniline are used.

3.4 Investigating the mechanical properties of polyaniline and polyaniline-iron-oxide-silver nanocomposites

The mechanical properties were performed by performing a tensile test on the polymer films. Based on the curves of stress-strain changes related to poly-aniline and its nanocomposites (Fig. 4), it was determined that by adding nanoparticles to the polyaniline, the resulting nanocomposite was reinforced, and its mechanical properties changed so that Young's modulus and strength at the breaking point were also increased compared to pure polyaniline. It seems that iron and silver nanoparticles, being placed between the polyaniline chains and the interaction that occurs between the hydrogen bonded to the nitrogen of the polyaniline chain and the oxygen of the nanoparticles, increase the tensile strength from 89 to 98 and 120 MPa to increase 10 and 15% of nanoparticles were converted to polymer. Nanoparticles turned into a polymer. Also, Young's modulus of pure polyaniline increased from 5.11 to 2.82 GPa for the nanocomposite containing 10% nanoparticles. It seems that since the iron oxide nanoparticle is a mineral and crystalline material and is harder than the polymer material, it leads to an increase in the composite modulus has been achieved.

3.5 Measuring the conductivity of polyaniline and its nanocomposites

The results of measuring the conductivity of polyaniline and polyaniline-iron oxide-silver nanocomposites are shown in Fig. 5. As it is clear in the figure, by adding nano-iron oxide-silver to the conductive polymer material, the electrical conductivity of the composite has decreased, with the addition of more nanoparticles to the conductive polymer, this decrease was greater so that adding 10% of nanoparticles causes a 15% decrease in conductivity and adding 15 The percentage of nanoparticles to polyaniline

decreased the conductivity by 30%. The addition of nanoparticles reduces the conductivity of polyaniline due to its semiconducting nature. Since the interaction between the N-H polymer chain and the surface of the nanoparticle is created, with the increase in the amount of the nanoparticle, this interaction increases, and of course, the conductivity of the resulting composite decreases. This is because in the polyaniline-iron oxide nanocomposite, compared to pure polyaniline, a part of the conductive material has been replaced by a semi-conductive material, and also, the conductivity in polyaniline is carried out due to the electron transfer through the hole mechanism, these transfers are mostly within the chains, but a part of the transfers also take place between the polymer chains, and the placement of a semi-conductor such as silver reduces the transfer of electrons between the chains, as a result of this, reducing the conductivity of the whole system.

4. Conclusions

In conclusion, this article has undertaken a comprehensive assessment of the utilization of MEMS magnetic electromechanical sensors within the sole of smart shoes, employing a polyaniline-nano iron oxide-silver nanocomposite fabricated via the solution casting method, specifically tailored for soccer training purposes. The properties of both polyaniline and its nanoparticles, spanning electrical, mechanical, and thermal stability, have been meticulously scrutinized. The examination revealed that the dispersion of nanoparticles within the polyaniline matrix notably enhanced its mechanical properties and thermal stability. The presence of iron-silver nanoparticles contributed to an overall fortification of the polyaniline composite, owing to their mineral nature and elevated thermal stability. The introduction of these particles resulted in a discernible augmentation of Young's modulus and strength at the breaking point of the polyaniline composites. Nevertheless, the incorporation of silver nanoparticles engendered a reduction in conductivity, attributable to their comparatively lower conductivity vis-a-vis polyaniline.

In a broader context, the incorporation of 15% nanoparticles into the polyaniline composite manifested a substantial 51% increase in the temperature at the onset of degradation. These findings underscore the heightened performance and improved thermal characteristics achieved through the integration of nanocomposites into the smart shoe sole, thereby highlighting their potential for optimization in soccer training applications. The systematic exploration of these material properties contributes valuable insights to the ongoing discourse on enhancing the efficacy of sports equipment through advanced materials and technology.

Acknowledgment

Project name: Research on smart sports innovation under the background of education informatization, Project number: ZD202318

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