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Polyester/Graphene Nanopowder (GNP) Pressure Garments as a Potential Use for Rehabilitation of Cerebral Palsy (CP)

Polyester/Grafen Nanotoz (GNP) Basınçlı Giysilerin Serebral Palsi (SP) Rehabilitasyonu Üzerine Etkilerinin İncelenmesi

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Araştırma Makalesi / Research Article

POLYESTER/GRAPHENE NANOPOWDER (GNP) PRESSURE GARMENTS AS A POTENTIAL USE FOR REHABILITATION OF CEREBRAL PALSY (CP)

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ABSTRACT: Cerebral palsy (CP) refers to a group of disorders that affect muscle movement and coordination. In many cases, vision, hearing, and sensation are also affected. One of the conditions is associated with contracture are occured when the muscles get locked in painful positions as CP is the most common cause of motor disabilities in childhood. According to the Centers for Disease Control and Prevention (CDC), it affects at least 1,5 to 4 out of every 1,000 children worldwide. In this study, warp knitted fabrics were designed of PET/ graphene nanopowder (GNP) yarns and then the fabrics were characterized with antimicrobial activity, electromagnetic shielding properties, differential scanning calorimetry (DSC) analyses, stiffness tests at MD and CD (machine and cross direction) and pressure measurements. Test results showed that the newly designed pressure garments will prevent complications, enhance the motor skills and ability to communicate for future designs during physical therapy rehabilitation.

Keywords: PET, graphene nanopowder, cerebral palsy, antimicrobial, electromagnetic shielding, pressure garments

POLYESTER/GRAFEN NANOTOZ (GNP) BASINÇLI GİYSİLERİN SEREBRAL PALSİ (SP) REHABİLİTASYONU ÜZERİNE ETKİLERİNİN İNCELENMESİ

ÖZET: Serebral palsi (SP) yani beyin felci kas hareketlerini ve koordinasyonunu etkileyen bozukluklar grubu ile ilgilidir. Birçok vakada, görme, duyma ve hissetme duyuları da etkilenmektedir. Koşullardan biri kontraktür ile ilişkilidir ve kaslar ağrılı pozisyonlarda kilitli kaldıklarında, SP çocuklukta en sık görülen motor sakatlık nedenidir. Hastalık Kontrol ve Önleme Merkezleri'ne (CDC) göre, dünya çapındaki her 1000 çocuktan en az 1,5 ila 4'ünü etkilemektedir. Bu çalışmada, çözgülü örme kumaşlar, PET/grafen nanotoz (GNP) ipliklerden tasarlanmış ve daha sonra antimikrobiyel aktivite, elektromanyetik ekranlama özellikleri, diferansiyel taramalı kalorimetre (DSC) analizleri, MD ve CD' yönlerinde (makine ve enine yönde) eğilme testleri ve basınç testleriyle ile karakterize edilmiştir. Test sonuçları, yeni tasarlanan basınç giysilerinin komplikasyonları önleyeceğini, motor becerilerini ve fizik tedavi rehabilitasyonu sırasında gelecekteki tasarımlar için iletişim kurma yeteneğini geliştireceğini göstermiştir.

Anahtar Kelimeler: PET, grafen nanotoz, serebral palsi, antimikrobiyel, elektromanyetik kalkanlama, basınçlı giysiler

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1. INTRODUCTION

Pressure garments have been shown to provide relief for CP sufferers. The entire suit acts as a soft exoskeleton that corrects abnormal muscle tone and re-trains a person's brain to recognize correct muscle movements.

1.1. Physical Therapy for Cerebral Palsy by Pressure Garments

They are effective immediately they are donned, providing much-needed dynamic compression to muscles with abnormal tone, sensory and proprioceptive feedback, as well as providing musculoskeletal alignment and stability. Applied pressures range between 0-200 mmHg according to CP types, body sizes, age and other conditions, which is in the optimal medical range. There are different compression garments available to help with these problems, including products from England's Gilbert and Mellish Limited and the Australian-based Second Skin. Both companies individually design each garment to meet each individual's postural and functional needs (see Figure 1) [1-5].

Figure 1. An illustration of the pressure garment use for a patient with cerebral palsy

Since elastic knitted fabrics take the highest proportion of the compression garments, the knitting construction takes an important action. Tricot, rachel, double-needle-bar –rachel are among the most preferred constructions in designs since these constructions show better elastic deformations in both wale and course directions. In this study, rachel warp knitted powernet construction design was used where the elastic yarns are as laid-in stitch to produce power-net construction [41].

Elastic based orthosis is expected to exert continuous and even pressure over the targeted limbs or body segment. This is because the orthosis is supposed to hold the limbs or body segment while the patient is not in a static position. Additionally, the pressure is supposed to work against the spastic muscles, thus reducing the spasticity. Consequently, providing stability to the patient's body segment, mainly during upright posture. As being determined in other medical products, it is also important to show the level of interface pressure exerted by elastic based orthosis. This way will provide evidence on how the orthosis works to ensure that the orthosis can be safely used [42-45].

Although Lycra orthoses have been used for around 10 years, there are very few research studies that have looked at the effectiveness of these garments. There are some short-term before and after studies, but long term effectiveness has not been evaluated. There has been one randomised controlled trial of the effectiveness of Lycra garments [6]. Nicholson et. al. studied an assessment of upper-limb function and movement in children with cerebral palsy wearing lycra garments were analyzed and the garments were found have showed improvements in at least one of the functional scales of Paediatric Evaluation of Disability Inventory (PEDI) [7]. In another research by Turner, many families and clinicians are interested in the outcomes of treatment using the Adeli suit (one of the commercial pressure garments) but the rehabilitation community does not have adequate scientific support for its use as a generally accepted treatment for cerebral palsy (CP). Very little research has been completed around non-traditional treatments such as AST [8]. It is also aimed to fulfill the literature in this area. According to a study conducted at Bobath Centre for Children with Cerebral Palsy in London, when the pressure garment continued to be worn, both the child and the parent perceived functional benefits and these were noticeable from the time that the child first wore the garment [9].

1.2. PET / Graphene Nanopowder (GnP) Melt Spun into Fibers

There are several studies on the chemically modified graphene synthesis. Xu and their team studied that at a low level of GnP loading, the PET matrix nanocomposite fibers were readily melt-spun without detecting fiber breakage or filament defect and exhibited mechanical properties similar to unmodified PET fiber as the compact interaction was formed between GnP and PET matrix. The volume resistivity of the resultant nanocomposite fibers was found to be substantially reduced due to the intrinsic electrical conductivity that the GnP imparts as a filler. [10-13]. When these nanoparticles are added during spinning processes, a more alignment and stable structure is provided in a study conducted by Kyoon Shin and their research team from the Center for Bio-Artificial Muscle and Department of Biomedical Engineering, South Korea [14]. The electrical conductivity of different carbon materials (multi-walled carbon nanotubes, graphene, carbon black and graphite), widely used as fillers in polymeric matrices, was studied using compacts produced by a paper preparation process and by powder compression [15]. It was found no research in the literature on fabrics formed by graphene nanoparticles nor any other nanoparticles meltspun into fibers, but there are many researches on coating of nanoparticles onto textile surfaces to impart different properties [36-38]. So this research will also fulfill the literature in this area and present more durable antimicrobial and electromagnetic shielding properties to newly designed textiles.

1.3. Antibacterial Properties of Graphene and Graphene Based Materials

The antibacterial activity of GO nanosheets towards various bacteria were studied researchers and it was found that GO nanosheets were more effective towards Gram-positive bacteria. A shematic diagram for the antibacterial activity of graphene oxide is presented in Figure 2. The antibacterial mechanism involved the generation of reactive oxygen species, which was confirmed using the electron spin resonance technique coupled with spin trapping technique. So GO nanosheets can be used as a potential antibacterial agent in future applications including nanomedicine and in many areas [19, 20].

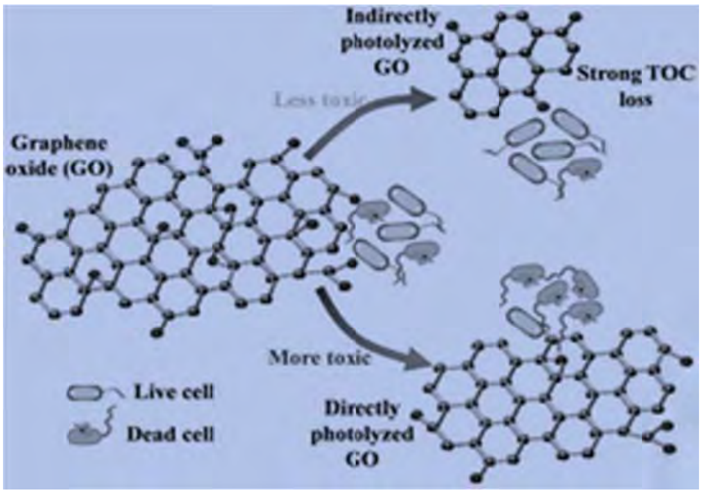


Figure 2. A shematic diagram for the antibacterial activity of graphene oxide [21]

Researchers by University of Texas, Austin, from Aerospece Engineering studied on the elastic bending modulus of monolayer graphene and they used a molecular mechanics approach, and explained the graphene monolayers rolled into carbon nanotubes [22]. In this research, the newly designed PET/GnP pressure garments would provide a long elastic and a strong structure during long use of training muscles. They would also provide a durable antimicrobial activity and an electromagnetic shielding effect to help the rehabilitation of people suffering from cerebral palsy.

2. MATERIALS AND METHOD

2.1. Materials

Polyester yarns meltspun with three different percentages (20 wt%, 25 wt%, and 30 wt%) of GnP were purchased from Toray Chemical Korea Inc. and knitted in powernet warp knit structure which is a raschel knit with inlaid yarns where each needle in the knitting width fed by at least one yarn and in line with the direction of fabric production. All fabrics were knitted at the weight of 170 g/m^2 and 0,57 mm thickness. Powernet warp knit structure is chosen due to its elastic structure and elastic recovery properties. The properties of the yarns are given in Table 1.

One of the most useful properties of graphene is that it is a zero-overlap semimetal (with both holes and electrons as charge carriers) with very high electrical conductivity. Carbon atoms have a total of 6 electrons; 2 in the inner shell and 4 in the outer shell. The 4 outer shell electrons in an individual carbon atom are available for chemical bonding, but in graphene, each atom is connected to 3 other carbon atoms on the two dimensional plane, leaving 1 electron freely available in the third dimension for electronic conduction. These highly-mobile electrons are called pi (π) electrons and are located above and below the graphene sheet. These pi orbitals overlap and help to enhance the carbon to carbon bonds in graphene. Fundamentally, the electronic properties of graphene are dictated by the bonding and anti-bonding (the valance and conduction bands) of these pi orbitals.

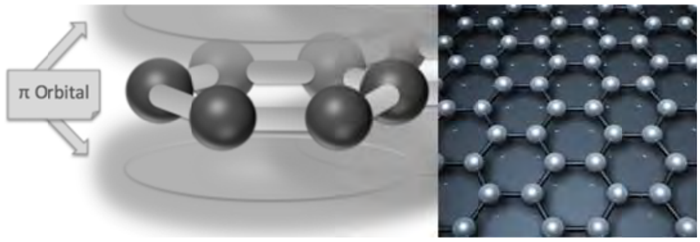


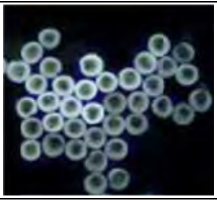
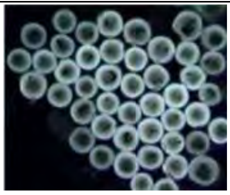
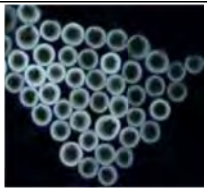
Figure 3. An illustration of the structure of graphene and its conductive structure

The electron cloud above and below each carbon ring overlaps creating a continuous pi (π) orbital across the whole graphene layer. The free movement of electrons across the whole graphene layer is what makes graphene highly conductive (see Figure 3).

In a study conducted by Hsu and their team it was found that the mechanical properties of graphene nanosheets/polypropylene composites increased dramatically with the increase in graphene percentages in the matrix [16]. In another study conducted by Wook Ha and their team it was found that, 5 wt % addition of GO incorporated into polyimide matrix increased the tensile strength and tensile modulus of the nanocomposite significantly [17]. Additionally, researchers from the School of Materials and National Graphene Institute, the presence of graphene even at very low loadings can provide significant reinforcement to the final material which means also a strong positive correlation with the materials modulus [18]. The percentages of GnP were chosen as 20 wt%, 25 wt%, and 30 wt%, and are labelled as A, B and C respectively to see also the effects of different percentages on antimicrobial activity, electromagnetic shielding properties, stiffness and exerted pressures of the materials.

The cross section of the PET/GnP yarns is also taken by an optical microscope and presented in Table 1. The microstructure of the carbon atoms arrangement and the homogenity of the crosslinking of GnP with PET can be seen clearly. It is also seen at yarn properties that type A yarn with 20% GnP showed higher tenacity as 3,0 cN/dtex. It showed a small but a significant decrease with the increase in the percentage of GnP which means a weakening of the bonds between each polymer.

Table 1. The properties of the PET/GnP yarns

Properties	PET/GnP Samples		
Type	A	B	C
Drawing Ratio	3.9	3.9	3.9
Linear Density (dtex) 36f	167.8	168.7	167.9
Tenacity (cN/dtex)	3,0	2,8	2,9
Tenacity CV (%)	4.82	4.89	4.07
Elongation (%)	31.5	37.6	38.3
Elongation CV (%)	6.5	4.0	7.8
Cross Section			

2.2. Antibacterial Activity

The experimental method used to determine the antimicrobial effects was AATCC Test Method 100: 2004 "Assessment of Antibacterial Finishes on Textiles" Standards, using Staphylococcus Aureus ATCC 6538 (2.00×10^5 CFU/ml) test inoculum [23]. The AATCC Test Method 61 (2A): 2010 "Colorfastness to Laundering: Accelerated" was followed to evaluate the washing durability. The samples were evaluated after 10 and 20 washes [24]. The variables were calculated from Equation (1) respectively.

$$R = \frac{100\,(C-A)}{C} \qquad (1)$$

where R is the percentage reduction of bacteria, A is the number of bacteria recovered from the inoculated treated sample and C is the number of bacteria recovered from the inoculated untreated control sample.

2.3. Electromagnetic Shielding Effect

The electromagnetic shielding properties were evaluated according to ASTM 4935; Standard test method for measuring the electromagnetic shielding effectiveness of planar materials [25]. This test method provides a procedure for measuring the electromagnetic (EM) shielding effectiveness of a planar material due to a plana- wave, far-field EM wave. From the measured data, near-field SE values may be calculated for magnetic (H) sources for electrically thin specimens. The measurement method is valid over a frequency range of 30 MHz to 1.5 GHz. The Shielding effectiveness (SE) is the ratio of power received with and without a material present for the same incident power. It is usually expressed in decibels by the following Equation (2).

$$SE = 10 \log \frac{P1}{P2} \text{ (decibels, dB)} \qquad (2)$$

Where:

P_1 = received power with the material present, and

P_2 = received power without the material present.

The measurements were taken from different parts of the samples between 30MHz- 1,5 GHz frequencies and repeated 10 times. The shielding effect datas were all obtained in dB unit. Then the obtained results were evaluated according to FTTS-FA-003 (2005) (Functional Technical Textile Standard) and presented in Table 2.

Table 2. Functional technical textile standard

Type	Degree	Shielding Effect	Category
Class I Professional Use	AAAAA	SE > 60 dB	Perfect
	AAA	60 dB ≥ SE > 50 dB	Very Good
	AAA	50 dB ≥ SE > 40 dB	Good
	AA	40 dB ≥ SE > 30 dB	Modarate
	A	30 dB ≥ SE > 20 dB	Low Modarate
Class II General Use	AAAAA	SE > 30 dB	Perfect
	AAA	30 dB ≥ SE > 20 dB	Very Good
	AAA	20 dB ≥ SE > 10 dB	Good
	AA	10 dB ≥ SE > 7 dB	Modarate
	A	7 dB ≥ SE > 5 dB	Low Modarate

Table 2 was used to determine the required shielding effect (SE) and % decrease in electrical field values for the significant shielding effect values.

2.4. Differential Scanning Calorimetry (DSC)

DSC Anayses were conducted to see the changes in thermal properties and a HITACHI 7020 model DSC measurement device was used to measure the melting point of the materials. Differential Scanning Calorimetry, or DSC, is a thermal analysis technique that looks at how a material's heat capacity (Cp) is changed by temperature. A sample of known mass is heated or cooled and the changes in its heat capacity are tracked as changes in the heat flow. This allows the detection of transitions such as melts, glass transitions, phase changes, and curing.

2.5. Physical and Mechanical Properties

Physical and mechanical properties were tested in order to evaluate the fabric properties in terms of stiffness. The samples were conditioned for 24 hours at 20^{o}C, 65% relative humidity in the physical testing lab before testing. Stifness was measured according to ASTM D5732, 2001 [26].

2.6. Pressure Measurements

The measurements were taken on each garment designed for calf and ankle (from ankle to knee) using a static mannequin and were tested using Tekscan wireless pressure sensors including ultra-thin and flexible printed circuit sensors with 10 repeats. Measurements were recorded using calibrated pressure sensors that were connected to a data acquisition and management software program by wireless transmitters.

2.7. Statistical Analyses

The statistical analysis of the experimental data was performed using JMP version 8.0.2 software package (SAS Institute, Inc., Cary, NC). The statistical analysis includes the analysis of variance (ANOVA). For the one-way ANOVA, p-values less than 0.05 were considered statistically significant. All of the data are also presented as avarage ± standard deviation.

3. RESULTS AND DISCUSSION

3.1. Antibacterial Activity

The antimicrobial properties of the control (100% PET fabric) and PET/GnP samples are presented in Table 3. The total population of Staphylococcus aureus (S. aureus) ATCC 6538 on each sample was determined. After the antimicrobial tests were performed, the live vibrio concentration of the standard blank sample at zero contact time, as well as that of a standard blank sample oscillated for 24h and that of the antimicrobial fabric sample oscillated for 24h, were compared. It was found that all samples showed a good antibacterial activity up to 20 washes. A small but a significant increase was observed with the increase in GnP concentration. It's attributed to antibacterial effects of GnP caused a small significant increase with the increase in concentration.

It was found no research on PET/graphene for antimicrobial purposes. In particular, a study [27] was investigated where a polyethylene terephthalate (PET) fabric was coated with reduced graphene oxide (RGO) sheets, and then a polypyrrole (PPy) layer was deposited by in situ polymerization in order to cover RGO. AATCC 100-2003 standard method was applied using *S. aureus* (ATCC 25923) and the samples showed excellent antibacterial activity [27, 28].

Table 3. Antibacterial activity using S. Aureus AATCC 6538

Samples	Test Organism: ATCC 6538 Staphylococcus Aureus (CFU/sample)		Percentage Reduction of Bacteria (R)
	Inoculated Sample at 0 contact time (cfu/mL)	Inoculated Sample at 24 hours oscillation (cfu/mL)	
Before Washing			
Control	0	0	0
Type A	$1.92x10^{5}$	$1.08x10^{4}$	92
Type B	$1.93x10^{5}$	$1.03x10^{4}$	95
Type C	$1.94x10^{5}$	$1.40x10^{3}$	99
10 Washes			
Control	0	0	0
Type A	$1.95x10^{5}$	$1.51x10^{4}$	92
Type B	$1.92x10^{5}$	$1.24x10^{4}$	94
Type C	$1.93x10^{5}$	$1.03x10^{4}$	95
20 Washes			
Control	0	0	0
Type A	$1.92x10^{5}$	$9.80x10^{4}$	49
Type B	$1.93x10^{5}$	$9.20x10^{4}$	52
Type C	$1.94x10^{5}$	$9.05x10^{4}$	53

Table 4. Electromagnetic shielding reference limits

SE (dB)	% Decrease in Electric Field	Evaluation
0 – 10	0 – 68,377	No Shielding Effect
10 – 30	68,377 – 99,838	Simple Shielding
30 – 60	99,838 – 99,900	Normal Shielding
60 – 90	99,900 – 99,997	Adequate Shielding
90 – 120	99,997 – 99,999	Almost Perfect Shielding
120 and above	99,999 and above	Maximum Shielding

3.2. Electromagnetic Shielding Effect

The highest and the lowest shielding effect frequencies used as reference values and the mean shielding effect values were calculated and evaluated using Table 4. The definition of screening effectiveness (SE) is directly related to an infinitely spread screening layer. The results of SE measurements depend on the method, frequency range, size of the sample and the properties of the material itself.

The mean SE values were found at the range of (22,03 dB-25,93 dB). The highest shielding effect was obtained at 86 MHz frequency. The highest SE was found at the highest SE value of 37,43 dB for type C (30% GNP concentration) and the results are presented in Table 5. The mean shielding effect value at the frequency of 0-1,30 GHz was found as 25,93 dB for type C which is at the range of 15-25 dB. A small but significant increase was observed with the increase in GNP concentration. When the fabrics were evaluated according to FTTS-FA-003 standard using Table 2, it was observed that they would provide a simple shielding and in the category of “very good” in general use class which means they would provide a modarate protection and the newly designed fabrics would help sensing and actuation for muscle training.

Khanam and their research team pointed out that Galpaya and Kuilla and their research group studied that the two parameters, electrical conductivity and percolation threshold are together associated with loading fraction, which is known as the percolation threshold (*pc*), the fillers form a network leading to a sudden rise in the electrical conductivity of the composites. Sometimes addition of a very low amount of conducting particles can make filler contact to form effective conducting paths and thus making the whole composite conductive [30-32]. Xie et al. observed that graphene is more effective for conductivity improvement than competing nanofillers such as CNTs because of their large specific surface area [33].

3.3. Differential Scanning Calorimetry (DSC)

The DSC analyses are conducted for 3 times for each sample and the results are presented as shown in Figure 4. According to the results, the graphics obtained from DSC curves, the melting temperature measured as 251.8^{o}C. It was shown that the introduction of GNP have lowered the melting temperature of PET from 260^{o}C to 251.8^{o}C. GNP decreased the crystalline density (cristallinity) of PET fibers, so this lowered the melting temperature. It can be concluded that the new materials would provide big advantages during processes such as dyeing and other treatments by energy savings in the future.

3.4. Stiffness

The results are presented in Figure 5. The stiffness showed a small but a significant decrease for all fabric samples with the increase in GnP concentration. This is attributed to GnP additions decreased crystallinity and increased the amorphousness and thus increased the softness and the pliability of the fabrics. In a study conducted by Abot and their team, it was observed that nanoparticle reinforcements created higher elasticity in the structure and Yan and their team fabricated flexible strain sensors using carbon/graphene composite nanofiber yarn and observed that the sensors showed an excellent flexibility and conductivity [34,35]. As a result, the decrease in GnP concentration created stiffer structures.

Table 5. Elecromagnetic shielding results

PET/GnP	Type A	Type B	Type C
Max. SE Value	32,29 dB	34,25 dB	37,43 dB
Min SE Value	11,77 dB	12,95 dB	14,42 dB
Mean SE Value	22,03 dB	23,60 dB	25,93 dB
Standard Deviation	0,16	0,17	0,19

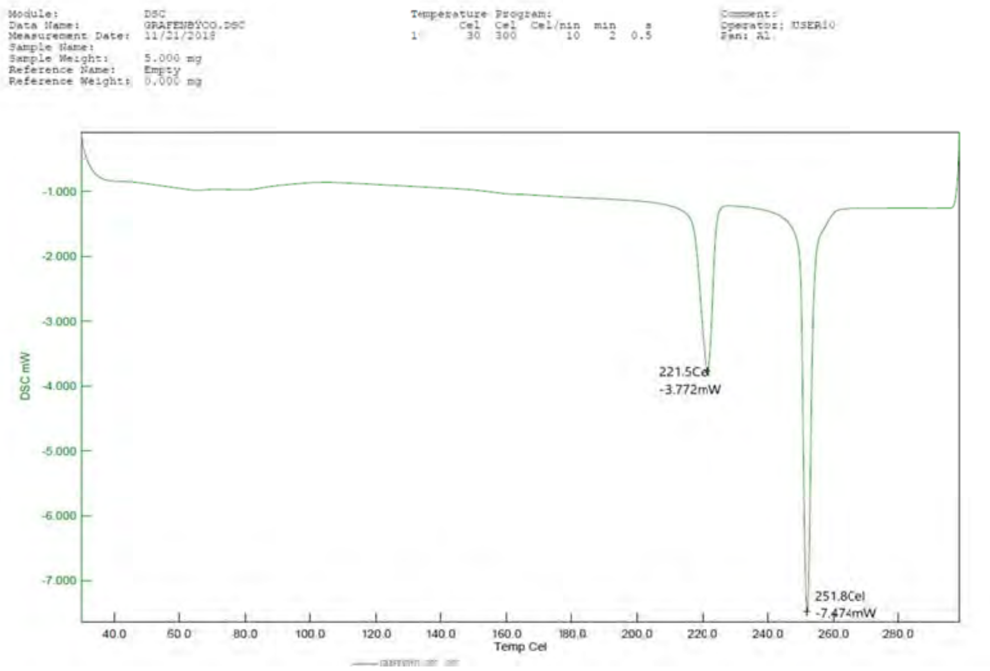


Figure 4. DSC analysis of PET/GnP fabrics

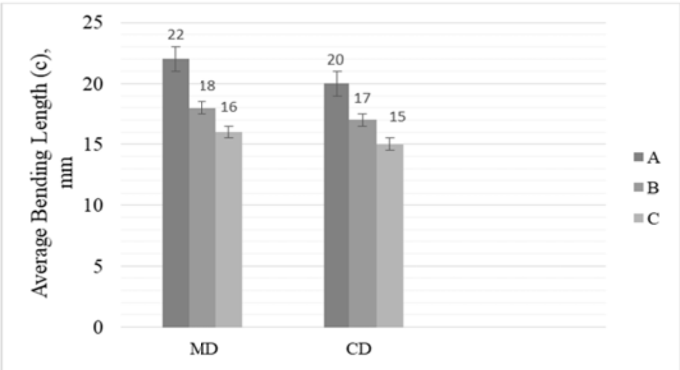


Figure 5. Stiffness (MD; machine direction and CD; cross direction) for PET/GnP fabrics; (A: 20% GnP, B: 25% GnP, C: 30% GnP)

A study by Kumar and their team confirmed that the stiffness properties are increased by the inclusion of graphene as nano-scale fillers in the matrix [29].

3.5. Effect of GnP Concentration on Stiffness

ANOVA one-way was used to analyze the effect of GnP on stiffness. Using one way analysis of variance, p-value was found as 0.0005. The result of the analysis is presented in Table 6. As p-value is smaller than 0.05, it can be estimated that GnP concentration has a significant effect on stiffness.

3.6. Pressure Measurements

The results are presented in Figure 6. Pressures measured for raw fabrics were found as 5.37 mmHg for ankle and 4.70 mmHg for calf. Pressures measured using wireless pressure sensors between 5.4 mmHg – 6.1 mmHg for ankle and 5 mmHg – 5.4 mmHg for calf which is in the required medical range. Following Laplace Theory, higher pressures were measured than pressures taken from calf. Mean scores of final pressures showed a small but a statistically significant increase with the increase in GnP concentration It is thought that the increase in nanoparticle concentration decreased the crystallinity and thus the amorphousness structure increased and created softer and more pliable fabrics. In a study conducted by Abot and their team, it was observed that nanoparticle reinforcements created higher elasticity in the structure and Yan and their team fabricated flexible strain sensors using carbon/graphene composite nanofiber yarn and observed that the sensors showed an excellent flexibility and conductivity [34,35].

Table 6. ANOVA and estimation of parameters from stiffness

ANOVA one way						
Source of Variance	SS	df	MS	F	P-value	F crit
Between Groups	425.0417	1	425.0417	16.4363	0.0005	4.3009
Within Groups	568.9167	22	25.85985			
Total	993.9583	23				

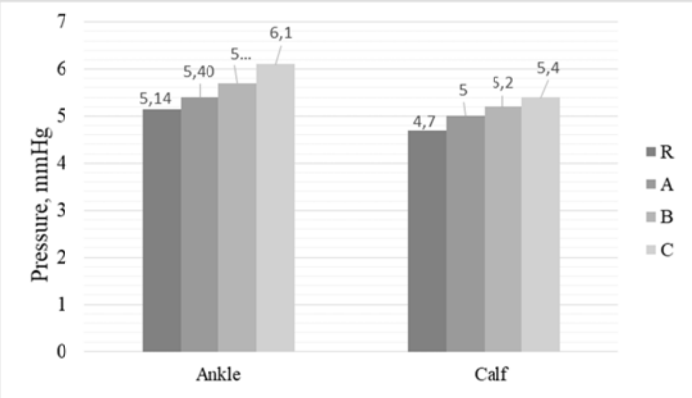


Figure 6. Mean scores of final pressures (mmHg) for PET/GnP fabrics; (R: Raw Fabrics, A: 20% GnP, B: 25% GnP, C: 30% GnP)

Currently the recommended pressure used for compression garment, medical compression stocking and sports garment ranges from 5 to 50 mmHg [46]. Athelets are wearing pressure garments for fewer muscle actions that ocur during running process [47,48]. It is also possible that the interface pressure produced by pressure garments provide continuous pressure which eventually reduces the spasticity in patients with CP. Since the measured pressures found in the range of 0-200 mmHg, the newly designed pressure garments will help during use of these garments.

3.7. Effect of GnP Concentration on Pressures

ANOVA one-way was used to analyze the effect of GnP on pressures. Using one way analysis of variance, p-value was found as 0.0178. The result of the analysis is presented in Table 7. As p-value is smaller than 0.05, it can be estimated that GnP concentration has a significant effect on pressure.

4. CONCLUSIONS

All fabrics have shown good antibacterial activity up to 20 washes. Type C samples showed better antimicrobial activity and it's attributed to higher percentages of GnP. When the fabrics were evaluated according to FTTS-FA-003 standard, it was observed that they are in the category of "very good" in general use class. But in professional use, shielding effects were found to be in adequate which means they would provide a modarate protection. The highest shielding effect was obtained at 86 MHz frequency and the highest SE was found at the highest SE value of 37 dB for all samples. The mean shielding effect value at the frequency of 0-1,30 GHz was found at the range of 15-25 dB. Type C GnP generally have provided higher electromagnetic interference–shielding effectiveness than type B and type C due to higher conductivity. A small but significant increase was observed in electromagnetic shielding effect with the increase in GNP concentration. DSC analyses have shown that the addition of GNP nanoparticles decreased the orientation of crystalline units inside the fibers and lowered the crystallinity of PET fibers which resulted as a small but a significant decrease in the melting temperature. According to DSC analyses, the new materials would provide big advantages during processes such as dyeing and other treatments by energy savings in the future. The stiffness showed a small but a significant decrease for all fabric samples with the increase in GNP concentration. Mean scores of final pressures showed a small but a statistically significant increase with the increase in GnP concentration. Finally, the newly designed PET/GnP pressure garments would provide a long elastic and a strong structure during long use of training muscles and help sensing and actuation. The acquired conductivity with GnP would help sensing with the needed tight structure onto limbs during physical therapy as suggested by the therapists [39,40]. They would also provide a durable antimicrobial activity and an electromagnetic shielding effect to help the rehabilitation of people suffering from cerebral palsy for future designs.

Table 7. ANOVA and estimation of parameters from pressures

Source of Variation	SS	df	MS	F	P-value	F-stat
Between Groups	92.3067	2	46.1533	36	0.0178	6.5107
Within Groups	63.7992	9	7.0888			
Total	156.1059	11				

REFERENCES

1. Attard, J., & Rithalia, S. (2004). *A review of the use of Lycra pressure orthoses for children with cerebral palsy.* International Journal of Therapy and Rehabilitation, *11*(3), 120-126.
2. Liptak, G. S. (2005). *Complementary and alternative therapies for cerebral palsy.* Mental Retardation and Developmental Disabilities Research Reviews, *11*(2), 156-163.
3. Footer, C. B. (2006). *The effects of therapeutic taping on gross motor function in children with cerebral palsy.* Pediatric Physical Therapy, *18*(4), 245-252.
4. Lee, I. H., & Park, S. Y. (2015). *Abnormal sitting pressures of hemiplegic cerebral palsy children on a school chair.* Journal of physical therapy science, 27(2), 499-500.
5. https://www.jobskin.co.uk/cerebral-palsy (Accessed on 19.01.2019).
6. Elliott, C., Reid, S., Hamer, P., Alderson, J., Elliott, B. (2011). *Lycra® arm splints improve movement fluency in children with cerebral palsy.* Gait & Posture, *33*(2), 214-219.

7. Nicholson, J. H., Morton, R. E., Attfield, S., Rennie, D. (2001). *Assessment of upper-limb function and movement in children with cerebral palsy wearing lycra garments*. Developmental Medicine and Child Neurology, *43*(6), 384-391.

8. Turner, A. E. (2006). *The efficacy of Adeli suit treatment in children with cerebral palsy*. Developmental Medicine and Child Neurology, 48(5), 324-324.

9. Knox, V. (2003). *The use of Lycra garments in children with cerebral palsy: A report of a descriptive clinical trial*. British Journal of Occupational Therapy, 66(2), 71-77.

10. Xing, L., Wang, Y., Wang, S., Zhang, Y., Mao, S., Wang, G., et al. (2018). *Effects of modified graphene oxide on thermal and crystallization properties of PET*. Polymers, 10(6), 613.

11. Verdejo, R., Bernal, M. M., Romasanta, L. J., et al. (2011). *Graphene filled polymer nanocomposites*. Journal of Materials Chemistry, 21(10), 3301-3310.

12. Xu, Q., Wang, C., Wang, B., Chen, Y., et al. (2017). *In situ polymerization and characterization of graphite nanoplatelet/poly (ethylene terephthalate) nanocomposites for construction of melt-spun fibers*. RSC Advances, 7(53), 33477-33485.

13. Dalton, A. B., Collins, S., Razal, J., Munoz, E., Ebron, V. H., et al. (2004). *Continuous carbon nanotube composite fibers: properties, potential applications, and problems*. Journal of Materials Chemistry, 14(1), 1-3.

14. Shin, M. K., Lee, B., Kim, S. H., Lee, J. A., Spinks, G. M., et al. (2012). *Synergistic toughening of composite fibres by self-alignment of reduced graphene oxide and carbon nanotubes*. Nature Communications, 3, 650.

15. Marinho, B., Ghislandi, M., Tkalya, E., Koning, C. E., et al. (2012). *Electrical conductivity of compacts of graphene, multi-wall carbon nanotubes, carbon black, and graphite powder*. Powder Technology, 221, 351-358.

16. Hsu, P., Chen, S., and Tsai, I. (2015). *Mechanical properties of graphene nanosheets/polypropylene composites*. In AIP Conference Proceedings (Vol. 1653, No. 1, p. 020045). AIP Publishing.

17. Ha, H. W., Choudhury, A., Kamal, T., Kim, D. H., et al. (2012). *Effect of chemical modification of graphene on mechanical, electrical, and thermal properties of polyimide/graphene nanocomposites*. ACS Applied Materials & Interfaces, 4(9), 4623-4630.

18. Papageorgiou, D. G., Kinloch, I. A., & Young, R. J. (2017). *Mechanical properties of graphene and graphene-based nanocomposites*. Progress in Materials Science, 90, 75-127.

19. Liu, S., Zeng, T. H., Hofmann, M., Burcombe, E., Wei, J., et al. (2011). *Antibacterial activity of graphite, graphite oxide, graphene oxide, and reduced graphene oxide: membrane and oxidative stress*. ACS Nano, 5(9), 6971-6980.

20. Krishnamoorthy, K., Umasuthan, N., Mohan, R., Lee, J., & Kim, S. J. (2012). *Antibacterial activity of graphene oxide nanosheets*. Science of Advanced Materials, 4(11), 1111-1117.

21. Hou, W. C., Lee, P. L., Chou, Y. C., & Wang, Y. S. (2017). *Antibacterial property of graphene oxide: the role of phototransformation*. Environmental Science: Nano, 4(3), 647-657.

22. Lu, Q., Arroyo, M., & Huang, R. (2009). *Elastic bending modulus of monolayer graphene*. Journal of Physics D: Applied Physics, 42(10), 102002.

23. AATCC 100-2004, (2010), Standard test method for the assessment of antibacterial finishes on textiles, *American Association of Textile Chemists and Colorists,* Philadelphia, PA.

24. AATCC Test Method 61 (2A)-(2010), Standad test method for the colorfastness to laundering: accelerated, *American Association of Textile Chemists and Colorists* Philadelphia, PA.

25. ASTM 4935, (1999), Standard test method for measuring the electromagnetic shielding effectiveness of planar materials, *American Association of Textile Chemists and Colorists* Philadelphia, PA.

26. ASTM D-5732-95, (2001), Standard test method for stiffness of nonwoven fabrics using the cantilever test, *American Association of Textile Chemists and Colorists* Philadelphia, PA.

27. Berendjchi, A., Khajavi, R., Yousefi, A. A., et al. (2016). *Improved continuity of reduced graphene oxide on polyester fabric by use of polypyrrole to achieve a highly electro-conductive and flexible substrate*. Applied Surface Science, 363, 264-272.

28. Periolatto, M., Ferrero, F., Vineis, C., Varesano, A., et al. (2017). *Novel antimicrobial agents and processes for textile applications*. In *Antibacterial Agents*. IntechOpen Ltd, London, UK.

29. Kumar, D., and Srivastava, A. (2016). *Elastic properties of CNT- and graphene-reinforced nanocomposites using RVE*. Steel and Composite Structures, 21(5), 1085-1103.

30. Khanam, P. N., Ponnamma, D., & Al-Madeed, M. A. (2015). *Electrical properties of graphene polymer nanocomposites*. In Graphene-based polymer nanocomposites in electronics (pp. 25-47). Springer Publishing Company, New York, USA.

31. Galpaya, D., Wang, M., Liu, M., Motta, N., Waclawik, E. R., et al. (2012). *Recent advances in fabrication and characterization of graphene-polymer nanocomposites*. Graphene, *1*(2), 30-49.

32. Kuilla, T., Bhadra, S., Yao, D., Kim, N. H., Bose, S., & Lee, J. H. (2010). *Recent advances in graphene based polymer composites*. Progress in Polymer Science, 35(11), 1350-1375.

33. Xie, S. H., Liu, Y. Y., & Li, J. Y. (2008). *Comparison of the effective conductivity between composites reinforced by graphene nanosheets and carbon nanotubes*. Applied Physics Letters, 92(24), 243121.

34. Abot, J. L., Song, Y., Schulz, M. J., & Shanov, V. N. (2008). *Novel carbon nanotube array-reinforced laminated composite materials with higher interlaminar elastic properties*. Composites Science and Technology, 68(13), 2755-2760.

35. Yan, T., Wang, Z., Wang, Y. Q., & Pan, Z. J. (2018). *Carbon/graphene composite nanofiber yarns for highly sensitive strain sensors*. Materials & Design, 143, 214-223.

36. Hebeish, A., El-Naggar, M. E., Fouda, M. M., Ramadan, M. A., Al-Deyab, S. S., & El-Rafie, M. H. (2011). *Highly effective antibacterial textiles containing green synthesized silver nanoparticles*. Carbohydrate Polymers, 86(2), 936-940.

37. Çakır, B. A., Budama, L., Topel, Ö., & Hoda, N. (2012). *Synthesis of ZnO nanoparticles using PS-b-PAA reverse micelle cores for UV protective, self-cleaning and antibacterial textile applications*. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 414, 132-139.

38. Becheri, A., Dürr, M., Nostro, P. L., & Baglioni, P. (2008). *Synthesis and characterization of zinc oxide nanoparticles: application to textiles as UV-absorbers*. Journal of Nanoparticle Research, 10(4), 679-689.

39. MacKenzie, C., & McIlwain, S. (2015). Evidence-Based Management of Postural Control in a Child with Cerebral Palsy. Physiotherapy Canada, 67(3), 245-247.

40. Flanagan, A., Krzak, J., Peer, M., Johnson, P., & Urban, M. (2009). *Evaluation of short-term intensive orthotic garment use in children who have cerebral palsy*. Pediatric physical therapy, 21(2), 201-204.

41. Xiong, Y., & Tao, X. (2018). *Compression garments for medical therapy and sports*. Polymers, 10(6), 663.

42. Abd El-Kafy, E. M. (2014). *The clinical impact of orthotic correction of lower limb rotational deformities in children with cerebral palsy: a randomized controlled trial*. Clinical rehabilitation, 28(10), 1004-1014.

43. Bahramizadeh, M., Rassafiani, M., Aminian, G., Rashedi, V., Farmani, F., & Mirbagheri, S. S. (2015). *Effect of dynamic elastomeric fabric orthoses on postural control in children with cerebral palsy*. Pediatric Physical Therapy, 27(4), 349-354.

44. Shaari, I., Osman, N. A. A., & Shasmin, H. N. (2018). *Interface pressure of lycra orthosis at different postures in children with cerebral palsy (CP)*. Sains Malaysiana, 47(4), 763-771.

45. Jin, Z. M., Ou, Y., Xu, N., & Yan, Y. X. (2013). *Pressure analysis on medical compression hosiery and property research of lycra/nylon double wrapped yarn*. In Advanced Materials Research, 821 (1), 215-218, Trans Tech Publications.

46. Maklewska, E., Nawrocki, A., Ledwoń, J. & Kowalski, K. 2006. Modelling and designing of knitted products used in compressive therapy. Fibres and Textiles in Eastern Europe 14: 111-113.

47. Troynikov, O., Wardiningsih, W., Koptug, A., Watson, C. & Oggiano, L. 2013. *Influence of material properties and garment composition on pressure generated by sport compression garments*. Procedia Engineering 60: 157-162.

48. Wang, Y. & Zhang, P. 2013. *The effect of physical-mechanical properties on dynamic pressure of compression garment.* International Journal of Clothing Science and Technology 25: 131-144.