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Enhancing Electrical Conductivity Attributes of Knitted Polyester Fabrics Using ZnO Nano-particles

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This work was adopted to enhance the electrical conductivity of knitted polyester fabrics by incorporation of zinc oxide nanoparticle (NPs) into the fibre vicinity. Five structures of PIQUE knitted polyester fabric of variable loop length were treated with ZnO NPs using exhaustion technique. The treated fabrics were sewn using two types of stitches: namely three thread overedge (504) and five thread full overedge (516). The comfort attributes of the treated fabrics; Viz. electrical conductivity, air permeability, and water permeability were assessed. Physico-mechanical properties of the different treated and untreated fabrics were also evaluated. Atomic absorption spectrometry was used to trace the amounts of zinc ions incorporated onto the different treated structures. The alteration in the functional groups of the modified samples was monitored by FTIR spectroscopy. Scanning electron microscopy coupled with energy dispersive X-ray spectroscopy/elemental mapping were adopted to confirm the inclusion and distribution of ZnO NPs onto the modified polyester fabric. The treated polyester knitted fabrics showed enhanced electrical conductivity with improved comfort properties without adverse effect on their performance and appearance attributes.

Keywords: Polyester, Knitted, Fabric, Zinc Oxide, Nanoparticles, Comfort, Electrical Conductive, Stitches.

Introduction

Polyester fibres, the queen of fibres, are used in production of garments, curtain, cloths, automotive interior and many other technical applications. The different weaving structures of knitted fabrics make it comfortable, Viz. superior stretch and elasticity, an amenity of fit to body shape. They have pleasant soft touch and afford fresh-like feeling. Due to these outstanding characteristics, consumers preferred sportswear, casual wear, and underwear which are manufactured from knitted fabrics [1-2].

Weft knitted structures, especially those used for high functional performance garments, have distinguished features of form-fitting and elasticity by virtue of the capability of knitted loops to convert the shape under tension [3]. The knitted structure exhibits a looped yarn process which could be achieved manually for small-scale production or mechanically for mass production. The characteristic feature that distinguishes knitted fabrics from woven fabrics is that the former allows greater stretch.

In many textile processes, nanoparticles are utilized due to their versatile characters, such as the huge surface area which enables them to act as adsorbent and carrier for other substances. Mowafi et al. reported that incorporation of nano-sized metal particles into different macromolecules imparts new functions [4]; Viz. improved bactericidal properties, enhanced resistance to UV [5], induced electrical and thermal conductivity [6], amended tensile properties and crease recovery angle, better dyeability [7], and fire-resistivity [8].

Nano ZnO was found to act as antistatic finishing agent when applied to polyester fabric by pad-dry-cure process with improved antistatic property [9]. It was also used on polyester to

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increase its electrical conductivity without affecting its comfort attributes [10]. ZnO-soluble starch nano composites were also synthesized to impart antibacterial and UV-protection functions for cotton fabrics [11].

Limited number of research papers has been reported for imparting electrical conductivity to knitted fabric using conductive composite materials [12]. In this study, we adopt a simple and easily applicable method to impart electrically conductivity to knitted polyesters fabric using zinc oxide nano-particle without adverse effect on the their inherent properties.

Experimental

Materials

Scoured polyester (PET) knitted fabrics (PIQUE) of different structures were kindly supplied by a private sector in Seoul, South Korea. The yarn count is Ne 30, possessing the same twist coefficient (αe = 3.6). Table 1 summarizes the main characteristics, assessed in our labs, of the used five knitted PET fabrics. Zinc oxide nano-powder (>100 nm) particle size and ascorbic acid were supplied by Sigma Aldrich.

Table 1: Specification of polyester knitted fabrics (PIQUE)

Sample code	Loop length (mm)	Count of rows/inch	Count of columns/inch	Thickness (mm)	Weight (g/m^2)
1	2.5	37	57	0.71	1.64
2	2	56	62	0.79	1.58
3	4	32	47	1.25	2.86
4	3	36	55	1.05	1.36
5	3.3	36	56	1. 5	1.34

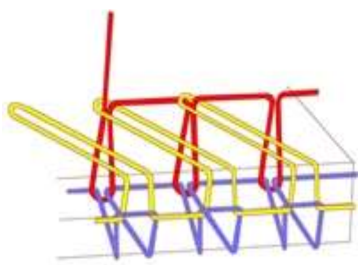
Method

Fabric Treatment

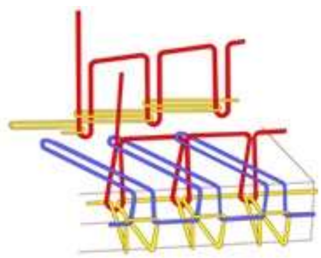
Polyester knitted fabrics of the declared fabric structures were treated with an 0.08 % (w/v) aqueous suspension of nano-ZnO at 70°C and pH 7 for 60 min with liquor ratio 1:30. The treated samples were then washed extensively several times with distilled water and left to dry at room temperature.

Sewing of Knitted Fabric

The fabric samples were sewn using two overlock stitches. The first: three- threads by Siruba model 737E specification 504M2-04, the second: five- threads by Siruba model 737D specification 516M2-35, as shown in figure 1.



(a) 504 – Three thread overedge



(b) 516 – Five thread full overedge

Fig 1: Two types of overlock stitches

Testing and Analysis

Comfort Characteristics

AC Electrical Conductivity

The electrical conductivity of untreated as well as treated fabrics before and after sewing was measured using LRC-bridge (Hioki model 3531zHi Tester, Japan).

Air Permeability

Air permeability of the examined fabrics was measured on FX 3300 air permeability tester (TEXTEST AG, Switzerland) at a pressure of 100 Pa according to ASTM D737 standard method.

Water Permeability

The water permeability of the treated as well as the untreated fabrics were assessed according to ASTM–D 1913 (American Test Method for

Water Repellency; Water Spray Test new edition 2010).

Physico-mechanical Properties

Surface Roughness

Surface roughness of treated and untreated fabrics was measured according to ASTM D7127-17- standard test method using surface roughness tester Model SE 1700∞ (Kosaka Laboratory Ltd. Japan).

Bending Stiffness

The bending stiffness of untreated as well as treated PET fabrics was determined according to the standard test method ASTM D1388-2018.The bending stiffness was taken as a measure of the fabric drapability.

Bursting Strength

The fabric bursting strength was tested by using Tinius Olsen material testing machine 500 according to ASTM D3787-2001 by applying 50 kgf load, 95 mm extension range, head speed of 305 mm/min, 90 mm endpoint and 0.1 kgf preload.

Chemical Analysis

Fourier Transforms Infrared Spectroscopy

Fourier transform infrared spectroscopy (FTIR) spectra of untreated as well as of treated samples were recorded by using an FTIR spectrophotometer (Nexus 670 Fourier transform infrared spectrometer; Nicolet, USA) in the region of 4000–400 cm-1 with spectra resolution of 4.0 cm^{-1}.

Atomic Absorption Spectrometry (AAS)

The metal content per gram of fabric was determined using flame atomic absorption spectrophotometer. Metal nano-particles on the different treated structures were extracted by immersing 0.2 g of the fabric in 20 mL of 15 wt% aqueous nitric acid at 80°C for 2 h. The concentration of zinc in the extract was measured by Contraa 700 flame atomic absorption spectrophotometer (AAS, Analytik, Jena, Germany) equipped with a zinc lamp at 213.9nm.

The Zn content in the fabrics was calculated according to equation (1) [13]

$X = C \times V / [W \times (1- MC/100)]$ …………. (1)

Where X is the metal ion content in the treated fabric (mg/g), C is the metal ion concentration (mg/L) in extracted solution, V is the volume of extracted solution (0.02 L),W is the weight of dried treated fabric (g), and MC is the moisture content in dried treated fabric (%).

Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy

Bruker Nano GmbH Scanning Electron Microscope D-12489 Berlin, Germany, was applied to investigate the morphological structure of the treated as well as untreated samples. The samples were mounted on aluminium stubs, and sputter coated with chromium in an S150A with 20 KV scanning voltage. The energy dispersive X-ray spectroscopy (EDX) measurements were reported at 20 KV accelerating voltage and 15 mm working distance. The distribution of particles' diameter was measured using Image J software program saved on scanning electron microscope (SEM).

Results & Discussion

Amounts of ZnO NPs taken by fabrics

The amounts of ZnO-NPs adsorbed by all modified fabrics were determined using AAS and the findings are summarized in Table 2.

The metal uptake shows its maximum value in sample number 2 and its minimum value at sample number 3. This can be correlated with the yarn counts of the different fabrics structures declared in Tables 1 and 2. These tables show that as the number of columns per inch increases, the zinc uptake by the fabrics is enhanced.

Table 2: Metal contents of the different structures treated polyester fabrics

Sample code	Zinc content (mg/g)	Fabric structure
1	4.1	
2	4.6	
3	0.7871	
4	1.3	
5	1.7	

Electrical conductivity (EC)

Knitted polyester fabrics with five different structures were evaluated for their electrical conductivity after being treated with nano-zinc oxide. Figure 2 shows the values of the EC the used untreated knitted fabrics as well as those of the corresponding treated structures after sewing with two types of stitches: three-thread overlock (504) and five-thread overlock (516).

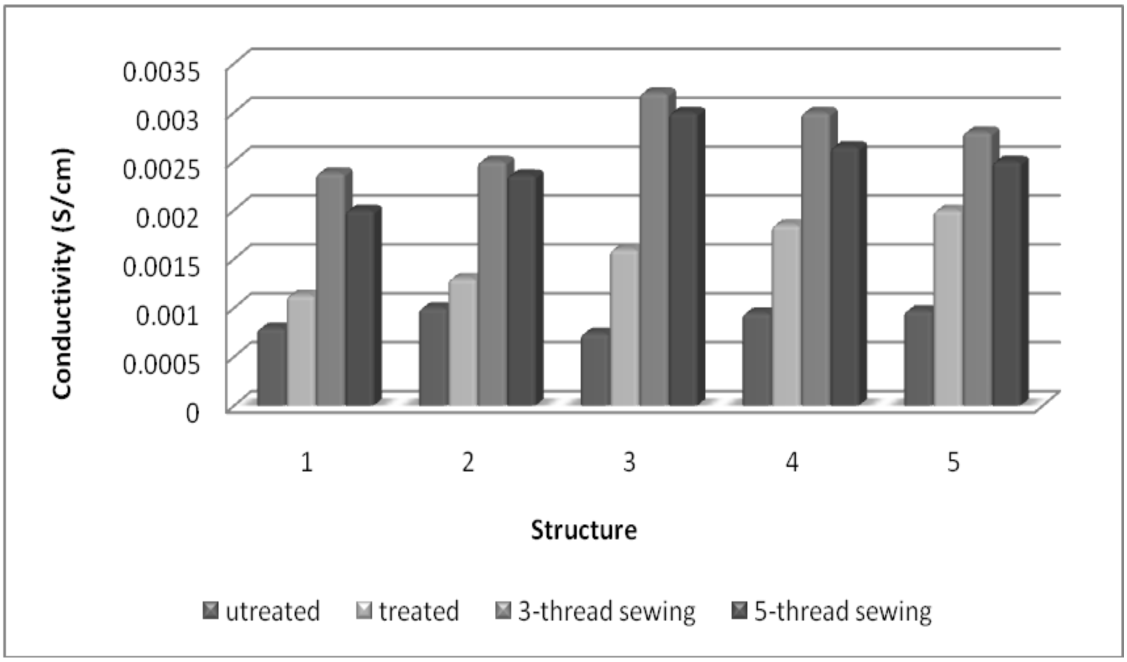


Fig. 2 electrical conductivity of 5-structures of knitted polyester fabric

The knitted fabrics are made up of a single yarn, looped continuously to produce a braided look, which make the electrical current continuous. While the woven fabric composed of multiple yarns crossing each other with right angles to form a grain, which causes continuous cut in the electric circuit of the passing current. The extent of improvement in the electrical conductivity of the treated fabrics is a function of the fabric structure. This can be correlated to the data of atomic absorption in table 2, where the Zn content increases in the order: structure 3 > structure 4> structure 5 > structure 1 > structure 2. Figure 2 reveals also that the EC of sample 3 is the highest among the other structures. Further increase in zinc concentration resulted in lower electrical conductivity. This can be rationalized in terms of the low concentrations of zinc leads to formation of percolated network and creates continuous connectivity between the small sized zinc particles [14]. The high concentrations of zinc represent the critical concentration at which formation of cluster starts which behaves as trapping centres of different depths. These finding are in harmony with the percolation theory of Scholl and Binder [15].

Moreover, the conductivity of the knitted treated fabrics after sewing increased, presumably due to the nature of the used stitch type which would enhance the electrical conductivity by making-up of "cut and sew" knitted garment. Moreover, sewing would gather more than one layer of the conductive layers within the fabric network, and improve the overall electrical conductivity [16].

Physico-mechanical Properties

Some of the physico-mechanical properties of the modified and native polyester fabrics were evaluated and the results were summarized in Table 3.

Data of this table implies that all metallized samples have better air permeability than the respective untreated ones. The flow rate of air across the fabric is highly affected by its porosity. The underlined data in Table 3 belongs to the fabrics with highest air permeability for each fabric structure. On the other hand, the water permeability exhibited by each treated fabric structure is almost similar as the respective untreated fabric. This means that metallization of knitted polyester fabrics has no appreciable effect on their water permeability.

Data of this table revels also that the ZnO NPs-treated fabrics has better drapability than the corresponding untreated sample as indicated from the bending stiffness data. The surface roughness of different fabric structures increases by metallization. The bursting strength of all fabrics was not affected by treatment by ZnO NPs.

Table 3: Physico-mechanical properties of the Nano-metal treated polyester knitted fabrics

Test	Sample No.	Polyester	
		Untreated	Treated
Air permeability ($cm^3/cm^2.S$)	Sample1	174.5	167.8
	Sample2	172	122
	Sample3	241	188
	Sample4	220	174
	Sample5	234	174
Water permeability ($cm^3/cm^2.L$)	Sample1	0.99	1.02
	Sample2	1.03	1.1
	Sample3	0.98	0.8
	Sample4	0.99	1.03
	Sample5	1.04	1.06
Bending Stiffness (cm)	Sample1	3.9	3.3
	Sample2	3.1	2.8
	Sample3	2.4	1.9
	Sample4	3.4	3
	Sample5	3.1	2.8
Bursting strength (Kg/cm2)	Sample1	9	9.6
	Sample2	9.6	9.8
	Sample3	13.6	13.7
	Sample4	11.8	12
	Sample5	13	13.4
Roughness (μm)	Sample1	16.77	18.05
	Sample2	16.31	19.89
	Sample3	14.07	17.44
	Sample4	22.78	23.29
	Sample5	23.37	25.58

Fourier transforms infrared spectroscopy

According to the data of figure 2 and table 3, sample 3 exhibits the best electrical conductivity with the least negative effect on its properties. Therefore, FTIR spectroscopy was adopted to assign any variation in the functional groups of polyester fabrics as a result of their metallization.

FTIR charts of the untreated as well as treated fabric were shown in figure 3. The weak-medium band at 2963 cm^{-1} corresponds to the (C—H) stretching vibration, the strong band at 1710 cm^{-1} for (C=O) stretching vibration, at 1243 cm^{-1} as a strong peak for C–O, and a strong band at 1093 cm^{-1} for C–O stretching vibration of primary alcoholic groups of the end groups of the polyester macromolecule. The intensities of the aforementioned bands increased in case of ZnO NPs-treated samples. Compared with the FTIR chart of untreated sample, no new bands were observed in the FTIR charts of the metalized fabric, which proves that no creation or disappearance of functional groups took place due to treatment of polyester fabrics with ZnO NPs

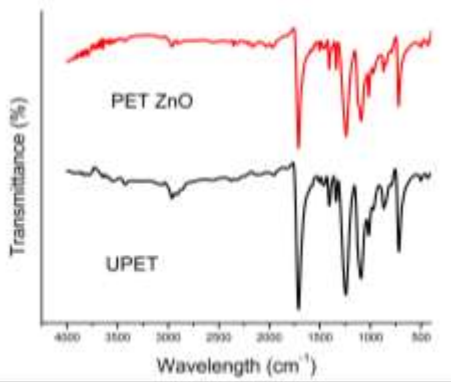


Fig. 3: FTIR spectra of structure 3, UPET fabric and PET treated with ZnO NPs

Microscopic Investigation

The change in the topographical properties of metallized-polyester fabric (sample 3) was studied using SEM and EDX (Figures 4 to 5).

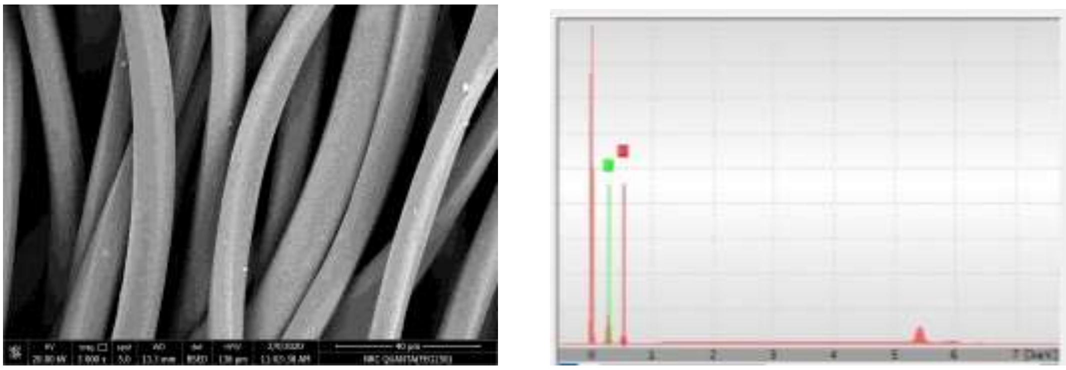


Figure 4: SEM and EDX analysis for the untreated polyester knitted fabric

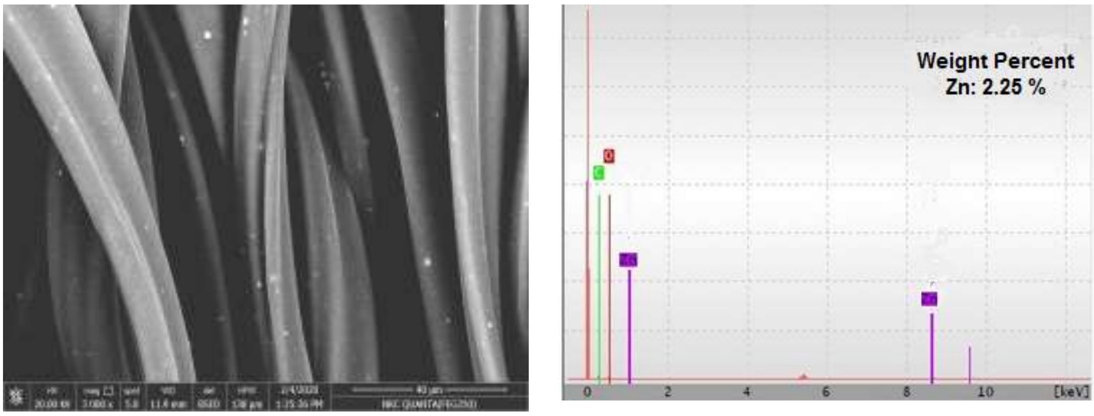


Figure 5: SEM and EDX analysis for the treated polyester knitted fabric

Figure 5 clarifies that the treated fabric was loaded with ZnO nano-particles. EDX was adopted to affirm the inclusion of the metal nanoparticles into the vicinity of the fabrics. Signals appear at ca. 1, 8.601 and 9.5 keV for Zn beside that around 0.5 keV for O [17].

In figure 6, EDX was used to map Zn NPs on polyester fabric, which proves that ZnO NPs are homogenously distributed all over the tested sample.

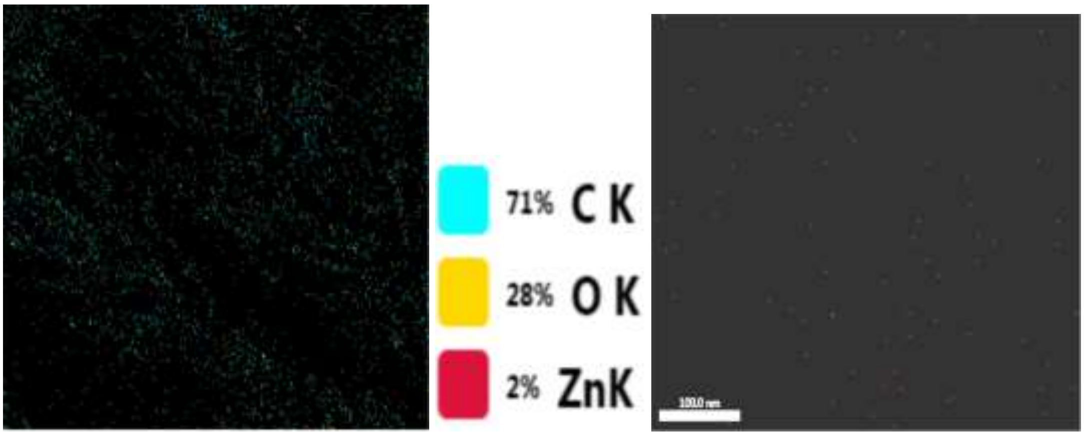


Figure 6: EDX mapping of ZnO NPs on polyester knitted fabric

Conclusion

Polyester knitted fabrics of different loop length were successfully treated with ZnO NPs to improve their comfort attributes. Metalized polyester fabrics exhibited enhanced electrical conductivity compared to the corresponding untreated sample.

The electrical conductivity of the treated samples after sewing was also found to be enhanced for the two stitch types. Different structures of knitted fabric were found to have different values of electrical conductivity, indicating that the structure of the fabric affects the metal uptake and consequently affects the electrical conductivity.

SEM and EDX were adopted to affirm the inclusion of ZnO NPs into the treated polyester fabrics. The proposed process has no negative impact on the comfort attributes and physico-mechanical characteristics of the metallized fabrics.

The proposed metallized knitted polyester fabrics could be a suitable nominee for the manufacture of conductive medical textiles used in physical therapy as suits.

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تحسين خواص التوصيل الكهربى لاقمشة البولى استر التريكو باستخدام جزيئات أكسيد الزنك النانومترية

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١ قسم بحوث صناعة الملابس والتريكو- المركز القومى للبحوث- ٣٣ ش البحوث- الدقى- الجيزة- القاهرة
٢ قسم الالياف البروتينية والصناعية- المركز القومى للبحوث- ٣٣ ش البحوث- الدقى- الجيزة- القاهرة

يهدف هذا العمل إلى تحسين التوصيل الكهربى لاقمشة البولى إستر التريكو عن طريق الادماج الداخلى لجزيئات أكسيد الزنك النامترية داخل المناطق البينية للالياف. تم معالجة خمس أشكال مختلفة من أقمشة البولى استر التريكو (PIQUE) ذات الاختلاف فى طول الغرزة بأكسيد الزنك النانومترية بإستخدام طريقة الحمام المائى. تم حياكة الاقمشة المعالجة بإستخدام نوعين من غرز الحياكة (الاوفر) باستخدام الثلاث خيوط (٥٠٤) و الخمس خيوط (٥١٦). تم تقييم خواص الراحة الملبسية للأقمشة المعالجة ومنها التوصيل للكهرباء، نفاذية المياه ونفاذية الهواء كما تم تعيين الخواص الفيزيقيه والميكانيكية المختلفة للاقمشة المعالجة وغير المعالجة. تم تحديد كمية أيونات الزنك داخل الأشكال المختلفة لاقمشة البولى استر المعالجة عن طريق الامتصاص الذرى الطيفى العنصرى. كما تم دراسة التغيير الكيميائى للاقمشة المعالجة عن طريق مطياف الاشعة تحت الحمراء هذا وقد أكدت صور الميكريسكوب الماسح الالكترونى ومطيافية تشتت الطاقة بالأشعة السينية والتوزيع العنصرى على ادماج جزيئات الزنك النانومترية وانتشارها داخل أقمشة البولى استر المعالجة. وقد أظهرت أقمشة البولى استر المعالجة تحسين التوصيل للكهرباء بالاضافة الى تحسين خواص الراحة الملبسية دون التأثير السلبى على سماتها الأدائية والمظهرية.