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Improvement of fabrics printability using metal oxides nanoparticles

Madiha Elkashouti, Hamada Mashaly, Meram Abdelrahman, Shimaa. S. M. Elhadad*

Dyeing, printing and auxiliaries dept; Textile Research and techonogy institute, National research center, El-dokki 12622, Egypt

Abstract

Functionalized textiles are very promising for wearable technologies. The main purpose of this study is to improve fabrics printability using metal oxides nanoparticles. Polyester/ cotton, PET, Cotton, Polyamide, and viscose were treated by using different nanoparticle metal oxides (MgO, ZnO, and TiO_2) with many ratios (0.5, 1, 1.5, 2%). In addition to that, the treated fabrics were printed by disperse dye red 60. The result shows, that the color strength of treated fabrics significantly improved in a comparison with untreated fabrics. Moreover, the mechanical performances of treated fabrics are also investigated.

Keywords: nanoparticles, metal oxides, printing fabrics, functional materials.

1. Introduction

Nanotechnology is an excellent technique for creating structures by controlling atoms and molecules, functional material on the nanometer scale [(1)]. The unique and new properties of nanomaterial get the attention of researchers and scientists. Moreover, using nanotechnology in the textile industry has increased rapidly. Nanotechnology uses in the textile sector have improved fabric durability, comfort, and sanitary characteristics while also lowering production costs. [(2)]. Different materials, such as polysaccharides, proteins, and synthetic polymers, can be used to make nanoparticles. The materials are primarily determined by factors such as the required nanoparticle size, inherent properties such as aqueous, stability, and solubility, surface characteristics such as charge and permeability, degree of biodegradability, biocompatibility, and toxicity, the release of the desired product, and final product antigenicity, among others. [(3)] The particle size has a big impact on how well they stick to the fibers. The larger particle agglomerates should be easily removed from the fiber surface, whilst the tiniest particle should penetrate deeper and cling tightly to the fabric matrix [(4)]. Fabric treated with MgO, ZnO, and TiO_2 nanoparticles replace active carbon textiles, which were previously employed as chemical and biological protective materials. Metal oxide nanoparticles are more promising. Titanium oxide and zinc oxides are non-toxic and stable at high temperatures and capable of photocatalytic oxidation [(5)]. Metal oxides of MgO, ZnO, and TiO_2 exhibit photo-catalytic ability, and photo-oxidation capacity against biological and chemical samples. The main research effort involving nanoparticles metal oxide focused on antibacterial properties.

The present work is prepared treated fabrics using MgO, ZnO and TiO_2 nanoparticles with different ratios and then, printed the fabrics. The printed treated fabrics show remarkable improvement in coloration in addition to the functionality of fabrics.

1. Experimental:

2.1 Material:

- Previous prepared metal oxides nanoparticles (MgO, ZnO, and TiO_2) were used. [(6)]
- Polyester/ cotton (122) g|m2, polyester (150) g|m2, cotton (158) g|m2, polyamide (100) g|m2 and viscose (110) g|m2 fabrics are designed and prepared for treatment. Supplied from El-Mahalla El-Kobra Textile Company, Egypt.
- Commercial disperse red 60 dye is used for printing paste. Supplied by sun colors @ company, Egypt.

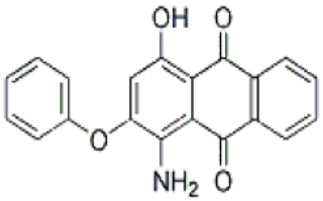

Fig 1: chemical structure of disperse dye (red 60).

*Corresponding author e-mail: shimaa.elhadad@yahoo.com. (Shimaa.S.M.Elhadad).
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2.3 Characterizations:

2.3.1 TEM microscopy:

The samples were evaluated using a TEM (Model EM-1230; Jeol, Germany) with a resolution of about 10 A and a high voltage (hV) of 100 kV. The volume or number of particles in the drop was used to determine the average vesicle size distribution.

2.3.2 Contact angle:

The contact angle was measured using a drop shape analysis (OCA 15 EC data physics; Germany).

2.3.3 Color strength measurements:

A Data Color SF 600 plus Colorimeter was used to measure the color strength (K/S) of each printed sample using a 9mm diameter measuring area. The Kubelka Munk equation was used to calculate the equivalent color strength value (K/S):

$$K/S = \frac{(1-R)^2}{2R}$$

Where, R = decimal fraction of the reflection of the dyed fabric, K = absorption coefficient, and S = scattering coefficient [7].

2.3.4 Antibacterial test:

Bacterial colony count was used to quantifying the antibacterial capabilities using the AATCC test method 100-1999. One Gram-positive Staphylococcus aureus (and one Gram-negative Escherichia coli) were utilized as non-spore producing bacteria. The bacterial colonies on the agar plate were counted, and the bacteria reduction rate by the treated fabrics was estimated using the equation below.

$$\text{Reduction rate (R) \%} = \frac{B - A}{B} \times 100$$

Where R is the % reduction of bacterial colonies, B is the number of the bacterial colonies of the untreated fabric (control) and A is the number of bacterial colonies after 18 hours in contact with the treated fabric. [8,9]

2.3.5 Fastness properties:

The fastness to rubbing, perspiration, washing, and light was tested. The colorfastness to rubbing was determined according to the AATCC test method 8-977. The colorfastness to washing was determined according to the AATCC test method 36-1972. The Colorfastness to light is determined according to ISO test methods 105-B01.

3. Methods:

3.1 Synthesis of MgO nanoparticles:

Sol-gel techniques were commonly used to synthesize MgO nanoparticles (10). To synthesize MgO nanoparticles, 100 g of MgCl was first dissolved in 500 ml of distilled water in a 1L beaker, followed by 50 ml of 1N NaOH solution. After that, the solution was vigorously agitated for four hours to produce magnesium hydroxide precipitates. To obtain the Mg (OH)2 gel, the suspension was centrifuged at 3000rpm for 5 minutes, washed multiple times with distilled water, and dried overnight at 60 0C. The dried powder was finally calcinated in the air under 450 0C for 2 hours and MgO nanoparticles were made.

3.2 Synthesis of ZnO nanoparticles:

ZnO nanoparticles were made by dissolving 98 percent $ZnCl_2$ in 200 mL water and heating it to 90 0C in an oil bath. Then, for 10 minutes at 90 0C, 16 mL of 5 M NaOH (pellet min. 99 percent) aqueous solution was added drop-wise to the zinc chloride solution with moderate stirring. Sedimentation was used to remove the particles from the supernatant dispersion. To drop the concentration of NaCl below 6-10M, the supernatant solution was removed and the remaining suspension was rinsed five times with distilled water.

The concentrated suspension and the washing solution were diluted at a 1:10 ratio each time. A solution of $AgNO_3$ was used to ensure that all of the NaCl had been removed from the suspension. The purified particles were next peptized in an ultrasonic bath for 10 minutes at ambient temperature with 2-propanol (98 percent). The peptization process is required to break up the micro-agglomerates and liberate the zinc oxide nanoparticles. After that, the particles were recovered by centrifugation for 15 minutes at 6,000 rpm. Three times the washing procedure was carried out. The production of ZnO is caused by the thermal treatment of the particles at 250°C for 5 hours.

3.3 Synthesis of TiO2 nanoparticles:

3.5 mL titanium tetrachloride ($TiCl_4$) was added to 50 mL deionized water in an ice bath in a fume hood, then 35 mL ethanol was added with vigorous stirring for 30 minutes at room temperature. To neutralize the titanium tetrachloride ($TiCl_4$), ethanol, and deionized water solution, drops of ammonium hydroxide were carefully added, and a precipitate was formed.

The solution was allowed to settle for twelve hours after vigorous stirring. The precipitate was centrifuged after that. The resulting precipitate was centrifugally separated after being rinsed with deionized water until the chloride ion was removed. The precipitate was then dried in an oven at 200°C for 4 hours to eliminate some of the absorbed water, yielding amorphous TiO_2.

The obtained amorphous TiO2 was calcined at 400°C for four hours in stages. The powder TiO_2 nanomaterial was finally obtained.

3.4 Prepared coated fabrics:

For treated fabric of PET/ cotton (122) g|m^2, PET (150) g|m^2, Cotton (158) g|m^2, Polyamide (100) g|m^2 and viscose (110) g|m^2 with different concentrations of MgO, ZnO and TiO_2 (0.5, 1, 1.5 and 2 %), the fabric samples soaked for 10 min in the previous ratios. Then the fabrics were padded to wet pick-up 80%. The padded fabrics were dried at 60 ◦C for 10 min and then cured at 160 ◦C for 5 min, followed by rinsing and drying.

3.5 Printing of coated fabrics:

- All treated fabrics were printed by transfer printing technique:
- Heat press Transfer machine 1400 W, 50 HZ, and 220 VAC.
- Printing paste recipe:

Dye 3gm Synthetic thickener
(Leuco print) 3gm
Water 94gm

100gm

- **Transfer printing conditions:**

Transfer printing temperature 170^0 C for 30 sec.

- **Printing paper:**

Uncoated paper of 70 gm., supplied by DA Alizay Company, France. The transfer paper was manually printed with the previous recipe using a silkscreen and then dried.

4. Results and discussion:

The main scope of the present work is to investigate the effect of the pretreatment of fabrics by metal oxides with different parameters to inform nano-form particles to improve the printability of polyester fabrics and the sublimation process of transfer printing.

For the accurate examination of particle size of synthesized NPs metal oxides TEM micrographs were investigated. Samples of polyester fabrics were treated with metal oxides in different ratios (0.5, 1, 1.5, and 2%). The pretreated fabrics were subjected to print with dispersed dye, followed by fixation, washing, and drying. The color strength, as well as colorfastness properties of treated fabrics, was investigated. The presence of metal oxides on the surface of fabrics leads us to multifunctions of fabrics such as antibacterial and hydrophobicity properties. The antibacterial properties and contact angle by the contact angle of treated fabrics were also investigated.

4.1 Characterization:

4.1.1 TEM microscopy:

Figs (2,3 and 4) represented transmission electron microscopy of ZnO, TiO_2 and MgO respectively. To our purpose, TiO_2, ZnO and MgO in the nanoparticles form were prepared. The particle size of the prepared metal oxides was monitored using transmission Electron Microscopy (TEM). To start with TEM investigation of the particle size of the synthesized metal oxides.

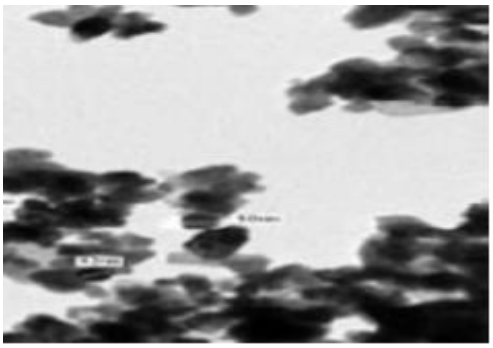

Fig 2: TEM of ZnO nanoparticles

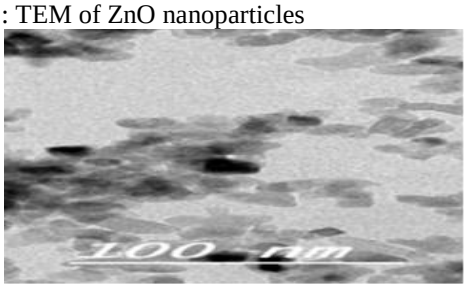

Fig 3: TEM of TiO_2 nanoparticles

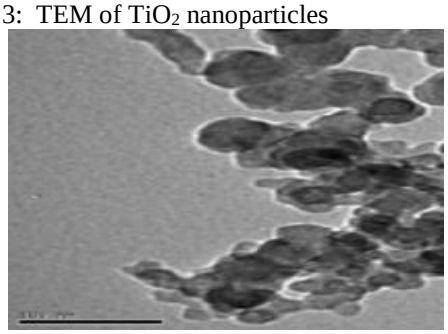

Fig 4: TEM of MgO nanoparticles

The morphology and structure of the obtained metal oxides nanoparticles were fully analyzed by TEM. The TEM results show the particles size of synthesized metal oxides in Nano-form ranging from 10 to 42 nm.

4.1.2 Antibacterial activity:

When the basic requirements of moisture, oxygen, nutrients, and an appropriate temperature are met, fabrics are good substrates for the growth of microbes. Natural fabrics, such as cotton, are more susceptible to microbial attack. The fungus normally exists in the human body and skin. It was found that antibacterial properties could be achieved on the textile fabrics by applying NPs metal oxides treatments.

MgO, ZnO, and TiO_2 were studied in selected samples from a 2% ratio. Using both gram positive (Staphylococcus aureus and Bacillus subtilis) and

gram negative bacteria, samples were tested for antibacterial activity (Pseudomonas aeruginosa and E.coli). The optical density of the various microbial strains was determined by adding samples to a 5 mL nutrient broth culture, which was then inoculated with 50 mL of bacterial fresh cultures and cultured at 37 °C for 24 hours in a shaking incubator at 150 rpm. At 620 nm, microbial growth was monitored, and the results were represented as a percentage of growth inhibition.

The antibacterial activity of treated fabrics is represented in table (1)

Samples	Antibacterial activity (%)			
	Gram positive		Gram negative	
	Staph. aureus	*Bacillus cereus*	*Pseudomonas Auroginosa*	*E. Coli*
Polyamide blank	0.0	0.0	0.0	0.0
Polyamide (MgO)	13.5	18.9	7.0	12.7
Cotton blank	0.0	0.0	0.0	0.0
Cotton (TiO_2)	44.3	7.7	18.3	28.5
Cotton (ZnO)	52.5	66.9	60.2	53.5
PET|Cotton blank	0.0	0.0	0.0	0.0
PET|Cotton (TiO_2)	38.8	5.3	63.2	57.0
PET|Cotton (ZnO)	19.8	13.2	9.5	7.5
PET blank	0.0	0.0	0.0	0.0
PET (TiO_2)	18.1	1.3	28.7	1.4
PET (ZnO)	50.4	63.7	12.8	28.7
PET (MgO)	4.0	18.6	34.6	49.9
Viscose blank	0.0	0.0	0.0	0.0
Viscose (TiO_2)	43.6	54.8	20.8	34.1
Viscose (TiO_2)	50.5	51.1	30.4	51.8

Because of their broad-spectrum antibacterial properties, metal and metal oxide nanoparticles such as zinc oxide (ZnO), manganese oxide (MgO), and titanium dioxide (TiO_2) compounds have gotten a lot of interest. The antibacterial activity of metal oxide nanoparticles were shown in Table 1. PET|Cotton treated with TiO_2 had strong antibacterial action against Pseudomonas auroginosa and E. coli, both gram negative bacteria. ZnO nanoparticles, on the other hand, demonstrated a wide range of antibacterial activities, particularly in cotton treated with ZnO, which exhibits broad-spectrum activity against gram positive (Staph. aureus and Bacillus cereus) and gram negative (Staph. aureus and Bacillus cereus) bacteria (Pseudomonas auroginosa and E. coli).

Several antibacterial mechanisms have been hypothesized to explain the antibacterial activities of metal nanoparticles, including the generation of reactive oxygen species (ROS), the interaction of nanoparticles with bacteria, resulting in bacterial cell damage, and alkaline effects. Several comparable mechanisms have been proposed to explain the inhibitory impact of metal nanoparticles on bacteria, such as the microbial inhibition of silver nanoparticles. Silver's antibacterial processes could involve inducing oxidative stress through the production of reactive oxygen species (ROS), which could lead to cell membrane breakdown.

4.1.3 Contact angle:

By producing nano-whiskers that are hydrocarbons and 1/1000 the size of a regular fiber, nano-treated cloth increases the water-repellent characteristic of the fabric. Water remains on top of the whiskers and above the fabric surface because the spaces between the whiskers on the fabric are smaller than a typical drop of water but still larger than water molecules. [11] A hydrophobic property can be imparted to fabrics by treating it with a thin nanoparticulate metal oxide film.

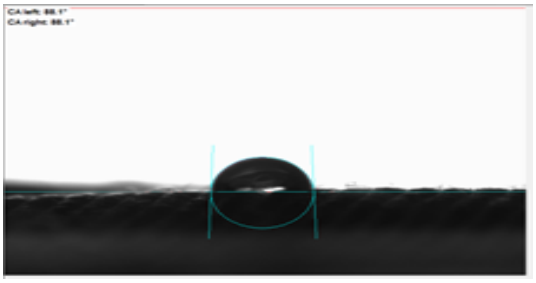

Fig 5: Treated Viscose with TiO_2

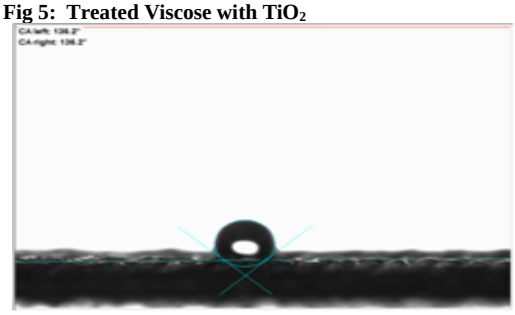

Fig 6: Treated PET/cotton with MgO

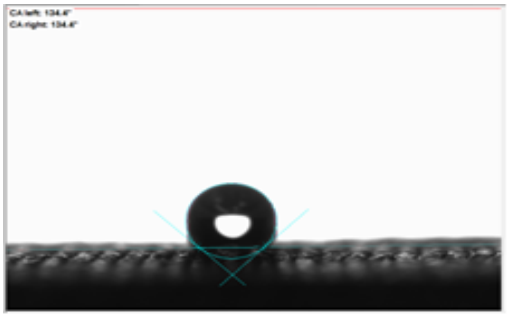

Fig 7: Treated PET with ZnO

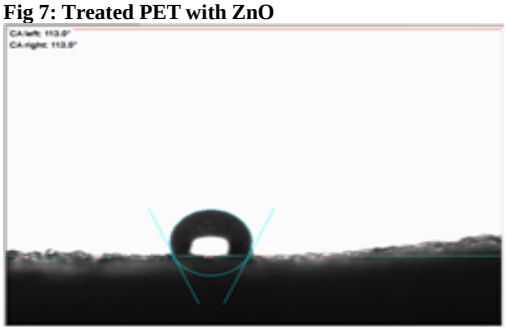

Fig 8: Treated PET/cotton with ZnO

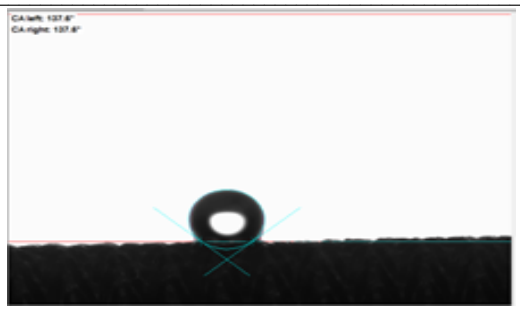

Fig 9: Treated Cotton with ZnO

Figs (5,6,7,8 and 9) represented the hydrophobicity of selected fabrics. These results indicate that, the hydrophobicity of the fabrics is due to the metal oxides treatment. The average contact angle results for all selected samples (Viscose TiO2, PET MgO, PET ZnO, PET/cotton ZnO, and Cotton ZnO) (116 º, 136 º, 134 º, 113 º, and 137 º) respectively. This means that all of the treated fabrics have increased to a high extent due to NPs metal oxides treatment.

4.1.4 Color strength measurements K|S:

The needed design is initially printed onto the paper carrier using traditional methods; most commonly screen printing, in transfer printing. The inks are made up of finely dispersed dyes, and the design can be transferred from paper to cloth by using a heat press to bring the paper into contact with the textile. The colors sublime and diffuse into the materials, permanently coloring them. This process is best applied to fabrics that would readily receive the sublimed disperse dyes. This simple, flexible process has numerous advantages, including low maintenance costs and the ability to produce almost no effluent. [12] The present work focused on using metal oxides nanoparticles NPs (MgO, ZnO, and TiO_2) to improve printing properties. In addition to that, NPs treated natural, synthetic, and blended fabrics by increasing the dye affinity and evaluation of colorfastness and antibacterial of NPS treated fabrics.

4.1.4.1 Color strength (K|S) of natural fabrics:

The main purpose of the research is to increase the affinity of dyeability of natural fabrics printed by disperse dyes. So, treated fabrics with NPs metal oxides get a chance to increase the dye affinity of natural fabrics with dispersed dye by using the transfer sublimation printing technique.

The K|S values of treated fabrics depended on: a) Nature of NPs metal oxides used. b) Metal oxides NPs concentrations. c) Type of fabrics used as a receptor surface.

Figs (10, 11, and 12) represented the color strength of untreated and treated printed natural fabrics (cotton, viscous) with different ratios of NPs metal oxides (MgO, ZnO, and TiO_2) using disperse red 60.

It is clear from color strength (K|S) data that higher color strength values while using NPs metal oxides (MgO, ZnO, and TiO_2).

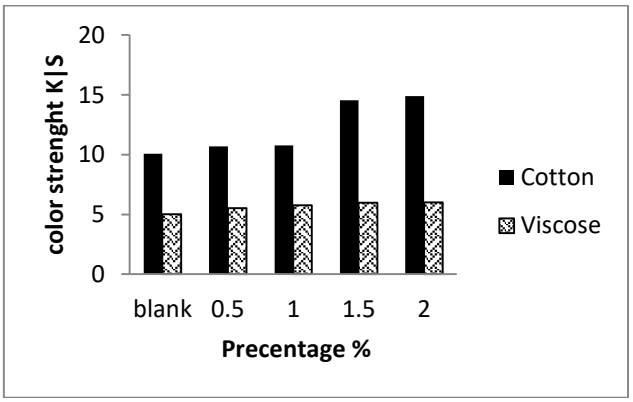

Fig 10: Color strength of treated natural fabrics, transfer printed with MgO using ratios (0.5 to 2 %)

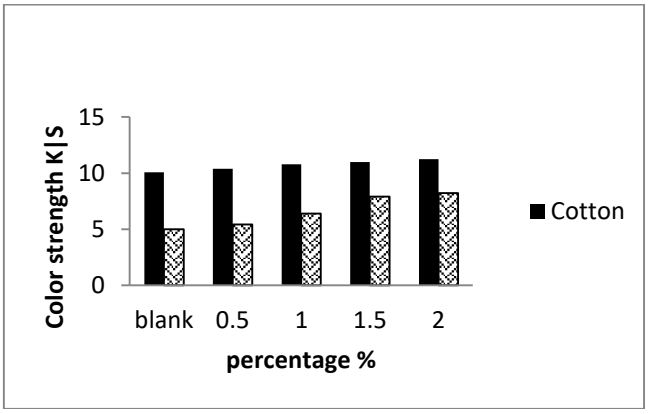

Fig 11: Color strength of treated natural fabrics, transfer printed with ZnO using ratios (0.5 to 2 %)

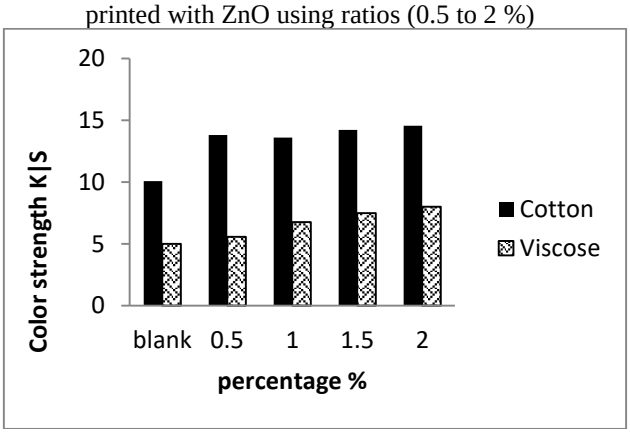

Fig 12: Color strength of treated natural fabrics, transfer printed with TiO_2 using ratios (0.5 to 2 %)

It is noticed that treated natural fabrics (cotton and viscose) get higher K|S values in a comparison with untreated fabrics. Also increasing K|S values were noticed by increasing metal oxides concentrations. It is significant to increase K|S values to 1.5 and 2 then

0.5 and 1 %. For example, treated cotton fabrics with MgO nanoparticles increased K|S values with different ratios from (10) un-treated to (10.3-10.4-14.4 and 14.5), (0.5, 1, 1.5, and 2) respectively. It is clear from K|S data remarkable increase in 1.5 and 2 % ratios. This means increasing the concentration of NPs MgO on the surface of cotton fabrics achieved a remarkable increase in color shade value. This is a remarkable achievement for printing natural fabrics (cotton and viscose) by using disperse dyes.

4.1.4.2 Color strength (K|S) of synthetic fabrics:

Figs (13, 14, and 15) represented the color strength of untreated and treated printed synthetic fabrics (polyester, polyamide) with different ratios of NPs metal oxides (MgO, ZnO, and TiO_2) using disperse red 60.

It can obviously from the K|S value data indicator that also the treated synthetic fabrics with NPs metal oxides (MgO, ZnO, and TiO_2) cause a significant increase in K|S values in untreated fabrics. For example, treated polyester fabrics with MgO nanoparticles increased K|S values with different ratios from (4) un-treated to (5.1-6.9-9 and 9.2), (0.5, 1, 1.5, and 2) respectively. As we mentioned before, the K|S values remarkable increase in 1.5 and 2 % ratios. We found the same trend in natural fabrics' K|S values by increasing concentration ratios of NPs metal oxides. These phenomena may be due to increasing concentration leading to an increase in inactivate surface as a receptor to dye that made the surface more ready to dye affinity.

4.1.4.3 Color strength (K|S) of blended fabrics:

The development of methods to enable multiple substrates such as blended fabrics to be dyed or printed by one class of dye is desirable. One approach is to derivative fibers to treat their properties, For instance, by reacting colorless hydrophobic groups onto cotton or wool to make the fiber substantive.

Figs (16, 17, and 18) represented the color strength of untreated and treated printed blended fabrics (polyester|Cotton) with different ratios of NPs metal oxides (MgO, ZnO, and TiO_2) using disperse red 60.

The same disprese dye red 60 used to transfer print the untreated and treated PET|C fabric modification was carried out using NPs metal oxides (MgO, ZnO, and TiO_2) with different ratios (0.5,1,1.5 and 2) . Again, similar trends to these were obtained with the corresponding treated, natural, and synthetic fabrics.

It is a clear significant increase of K|S values between untreated and treated fabrics, For example, the color strength of PET|Cotton treated by MgO remarkable increasing (10.5-10.6-10.9 and 12) with ratios (0.5,1,1.5 and 2 %) respectively than untreated (7.7). These results indicate to improve in the surface of blended as a receptor surface on the transfer printing technique.

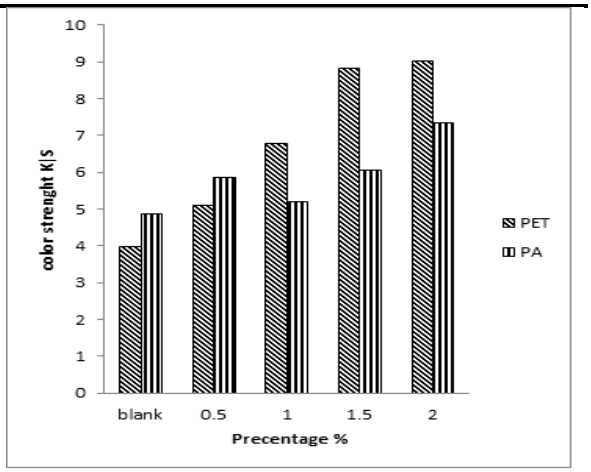

Fig 13: Color strength of treated synthetic fabrics, transfer printed with MgO using ratios (0.5 to 2 %)

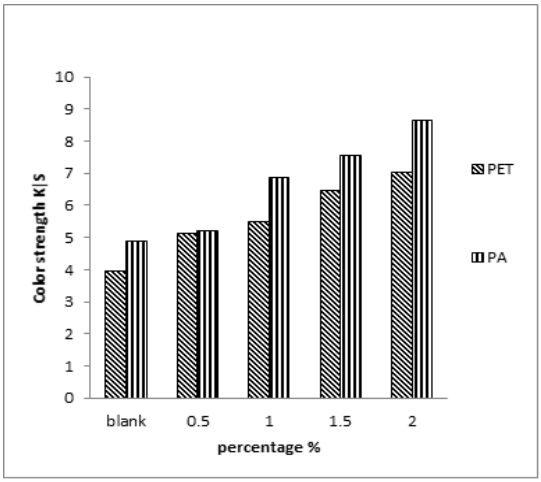

Fig 14: Color strength of treated synthetic fabrics, transfer printed with ZnO using ratios (0.5 to 2 %)

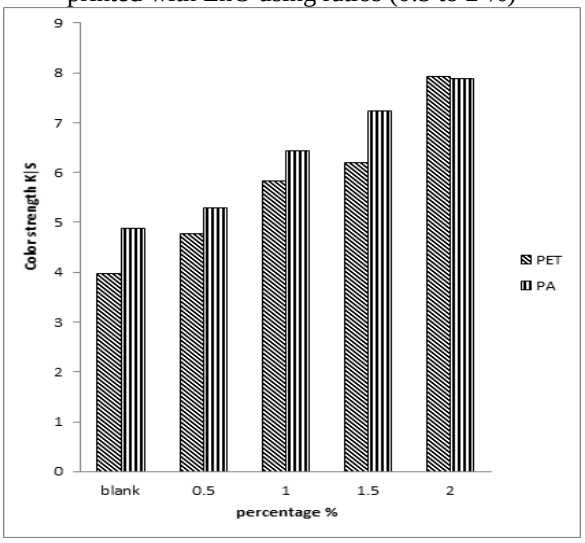

Fig 15: Color strength of treated synthetic fabrics, transfer printed with TiO_2 using ratios (0.5 to 2 %)

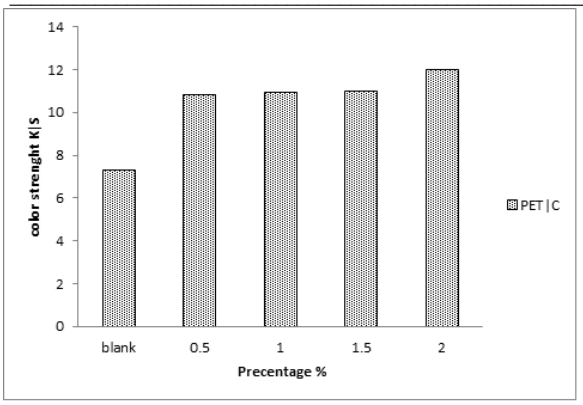

Fig 16: Color strength of treated blended fabrics, transfer printed with MgO using ratios (0.5 to 2 %)

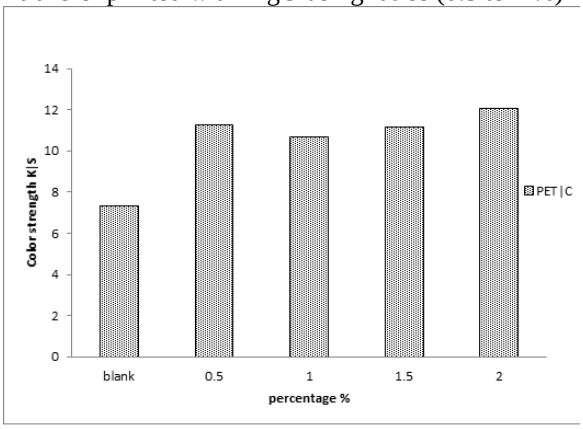

Fig 17: Color strength of treated blended fabrics, transfer printed with ZnO using ratios (0.5 to 2 %)

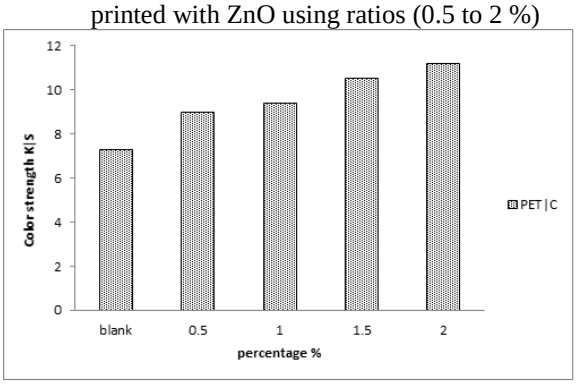

Fig 18: Color strength of treated blended fabrics, transfer printed with TiO_2 using ratios (0.5 to 2 %)

4.1.4.3 Color strength K|S of fabrics:

Figs (19, 20, and 21) represented the comparison of color strength of untreated and treated printed fabrics with different ratios of NPs metal oxides (MgO, ZnO, and TiO_2) using disperse red 60. Comparison of the printability and color strength results were obtained by NPs metal oxides in figs (19, 20, 21).

The color strength results shown in fig (19) showed that treatment of cotton, polyester/ cotton, polyester, polyamide, and viscose with magnesium oxides nanoparticles produced treated fabrics with a high value of color strength as compared with the results of the corresponding prints of the untreated fabrics. Also, increasing ratios from (0.5 to 2) % of MgO leads to remarkable increasing color strength values.

In figs (20, 21) the same trend shows that treated fabrics with ZnO and TiO_2 nanoparticles increase color strength values as compared with untreated fabrics.

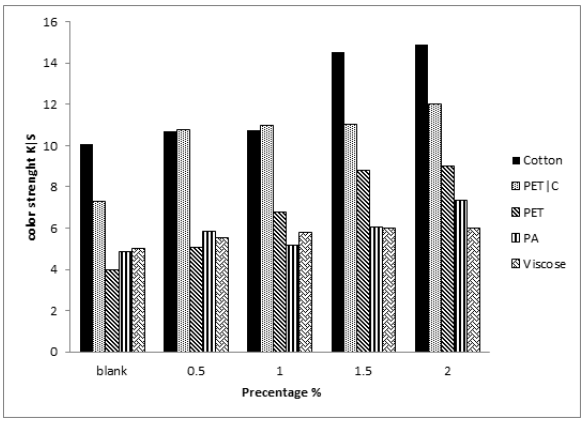

Fig 19: Comparison of Color strength of treated, transfer printed with MgO using ratios (0.5 to 2 %).

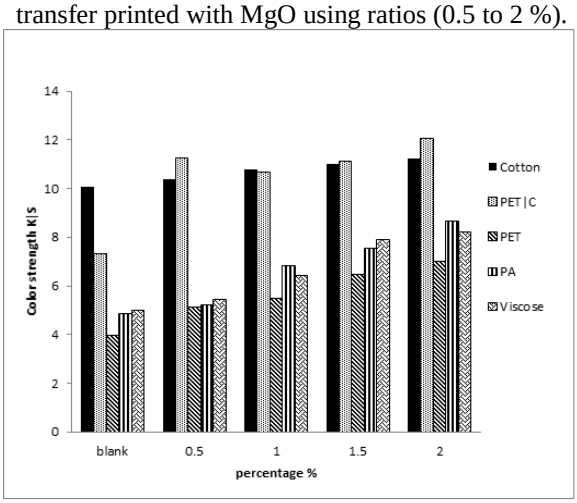

Fig 20: Comparison of Color strength of treated, transfer printed with ZnO using ratios (0.5 to 2 %).

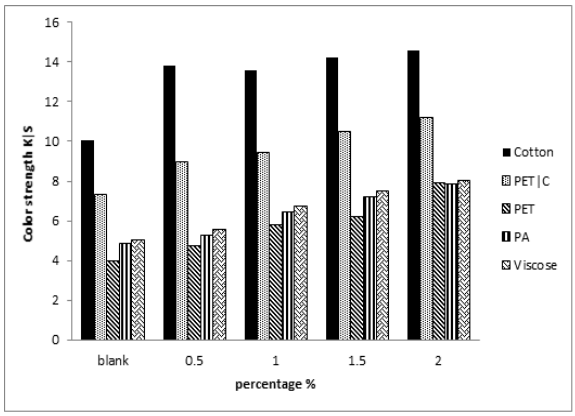

Fig 21: Comparison of Color strength of treated, transfer printed with TiO_2 using ratios (0.5 to 2 %).

Also, the color strength of PET|Cotton, and Cotton is higher than that of PET, PA, and viscous textiles, which could be due to the existence of high free OH-groups in cotton fabrics. These free hydroxyl groups increase the negatively charged surface of the spherical metal oxide nanoparticles, which bind with them. Many metal oxide NPs can easily improve the cellulose surface by introducing a +ve charged surface, similar to the case of protein fabrics, which increased the printability of these fabrics. It can be concluded that figs (19, 20, 21) a general trend is noticed in the color strength of treated fabrics by using metal oxides (MgO, ZnO, and, TiO_2) with different ratios (0.5, 1, 1.5, and 2 %). The results show that a color strength value is increases in treated fabrics than in un-treated fabrics.

The K/S values were discovered to be on the order of TiO_2 MgO ZnO nanoparticles, respectively.

However, there were differences in concentrations discovered. It's also obvious from the statistics that adding TiO2 nanoparticles resulted in a greater K/S value. It can also be shown that even at a smaller concentration of 0.5 percent TiO2 nanoparticles, the K/S increased from 10.5 MgO, 10.2 ZnO to (14) TiO_2.

It may be deduced from the previous work that treating cellulosic textiles with metal oxides in the nano-form, such as TiO_2, ZnO, and MgO, increases their printability with reactive dyes. The percent increase in K/S, on the other hand, is dependent on: a) the type of metal oxide employed, b) its concentration, and c) the type of fabric utilized.

5. Fastness properties:

One of the most important evaluations of the textile dryers & printers is the fastness properties of the dyestuffs in the market.

Therefore, evaluation of dye fastness properties of treated fabrics using different metal oxides nanoparticles in comparison to the corresponding untreated fabrics is considered of almost importance **(13,14 ,15).**

The fastness properties of untreated and treated printed fabrics with metal oxides nanoparticles (MgO, ZnO, and TiO_2) with a selected 2% ratio are represented in tables (2, 3, and 4).

In general, the fastness properties of all treated and printed natural (cotton, viscose), synthetic (PET, PA), and blended (PET|cotton) fabrics range from good to excellent ratings will all classes of metal oxides nanoparticles used as compared to the corresponding values for untreated and printed fabrics which range from moderate to very good in some cases.

Table 2: Fastness properties of untreated and treated transfer printed* fabrics with MgO nanoparticle**:

Type of fabric	Rubbing		Washing		Perspiration				Light fastness
	Dry	Wet	ST	ALT	Acidic		Alkaline		
					ALT	St	AlT	St	
Cotton treated by MgO	4-5	4-5	4	4	4	4	4	4	4
Untreated cotton	4	3-4	3-4	4	4	4	4	3-4	3-4
PET|C treated by MgO	4	4	4	4	4	4	4	4	4
Untreated PET|C	4	4	4	3-4	4	4	4	4	4
PET treated by MgO	4-5	4	4	4	4	4	4	4	4
Untreated PET	4	4	4	4	4	4	4	4	4
PA treated by MgO	4-5	4	4	4	4	4	4	4	3-4
Untreated PA	3-4	4	3-4	4	4	4	3-4	4	3-4
Viscose Treated by MgO	4	4	4	4	4	4	4	4	4
Untreated Viscose	4	3-4	4	4	4	4	4	3-4	4

***Using disperse red 60, Transfer temperature to 170 ºC for 30 sec.**

****With (2%) MgO nanoparticles.**

Table 3: Fastness properties of untreated and treated transfer printed* fabrics with ZnO** nanoparticle:

Type of fabric	Rubbing		Washing		Perspiration				Light fastness
	Dry	Wet	ST	ALT	Acidic		Alkaline		
					ALT	St	AlT	St	
Cotton treated by ZnO	4-5	4-5	4	4	4	4	4	4	4
Untreated cotton	4	4	4	4	4	4	4	4	4
PET|C treated by ZnO	4	4	4	4	4-5	4	4	4	4
Untreated PET|C	4	4	4	3-4	4	4	4	4	4
PET treated by ZnO	4-5	4	4	4	4	4	4	4-5	4
Untreated PET	4	4	4	4	4	4	4	4	4
PA treated by ZnO	4-5	4	4	4	4	4	4	4	3-4
Untreated PA	3-4	4	4	4	4	4	3-4	4	3-4
Viscose Treated by ZnO	4	4	4	4	4	4	4	4	4
Untreated Viscose	4	3-4	4	4	4	4	4	3-4	4

***Using disperse red 60, Transfer temperature to 170 ºC for 30 sec.**

****With (2%) ZnO nanoparticles.**

Table 4: Fastness properties of untreated and treated transfer printed* fabrics with TiO_2 ** nanoparticle:

Type of fabric	Rubbing		Washing		Perspiration				Light fastness
	Dry	Wet	ST	ALT	Acidic		Alkaline		
					ALT	St	AlT	St	
Cotton treated by TiO_2	4-5	4-5	4	4	4	4	4	4	4
Untreated cotton	4	3-4	3-4	4	4	4	4	3-4	3-4
PET|C treated by TiO_2	4	4	4	4	4	4	4	4	4
Untreated PET|C	4	4	4	3-4	4	4	4	4	4
PET treated by TiO_2	4-5	4	4	4	4	4	4	4	4
Untreated PET	4	4	4	4	4	4	4	4	4
PA treated by TiO_2	4-5	4	4	4	4-5	4	4	4	3-4
Untreated PA	3-4	4	3-4	4	4	4	3-4	4	3-4
Viscose Treated by TiO_2	4	4	4	4	4	4	4	4	4
Untreated Viscose	4	3-4	4	4	4	4	4	3-4	4

Using disperse red 60, Transfer temperature to 170 ºC for 30 sec.

*****With (2%) TiO_2 nanoparticles***

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