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Controlled nano-particle dyeing of cotton can ensure low cytotoxicity risk with multi-functional property enhancement

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Abstract

The Nanoparticle (NP) and their oxides are being progressively used and expected to be more frequently used in textiles. Nanoparticle (NP) has higher toxicological risk than larger particles because of their physicochemical properties, chemical reactivity and biological activity. In fact, the stability of nano-oxide particles in the medium is always challenging as they lack functional groups to leverage upon textile materials directly. Thus, in many finishing processes, cross-linkers and/or adhesives are applied together with NP at the cost of inferior comfort, feel and fastness which tends to be toxic and prone to release NPs under common laundering, physical stress and sweat. This study shows that the diffusion of NPs into the fibre polymer matrix via dyeing technique could be much durable, safer in terms of cytotoxicity levels and easy to process for tailoring desired functional attributes. We studied the possibility of a simple application technique via dyeing of vinyl sulphone based reactive dye with four kinds of NPs followed by their cytotoxicity test using cell line A431. 1% silica dyed sample have shown highest (198.5%) increase in tensile strength followed by 2% silica and 2% CNT whereas a decrease in elongation is highest in the case of CNT 2% (5.31%) and significantly enhanching the moisturemanagement properties in case of CNT and silica. The study showed promising results in dyeing with TiO2, CNT (Carbon nanotubes), Silica and Alumina NPs in enhancing the mechanical, moisture management, and surface frictional properties to ensure comfortable and safe wear.

Keywords: Nano- Textiles, Cotton, Cytotoxicity, Cell culture and toxicological assays, Moisture management test, Survivability analysis.

Introduction

The pros and cons of environmental nanotechnology are frequently reported now a days. Recent study by Chris Toumey [1] has specifically reported, the use and claims on silver NPs for cloth washing by Samsung. Samsung introduced silver NP-based washers for textile clothing that claimed 99.9% protection from bacteria and keeps away from nasty smells for thirty days with just one wash cycle. However, the net environmental toxicity is concerned [1]. Toxicological survey undoubtedly suggests[2-4] that many NPs have more risk of toxicity than larger particles because of their physicochemical properties, chemical reactivity (reactive oxygen species (ROS), including free radicals [5] resulting in oxidative stress, inflammation, prolong damage to proteins, membranes, and DNA [6] moreover, their biological activity are quite different[7,8]. Most of the other factors influencing toxicity are their shape, chemical composition, structure of the surface and charge, aggregation and solubility [9]. These can readily enter into the human body crossing membranes, cells, tissues, and organs compared to larger-sized particles[10]. They can be taken up by cell mitochondria[11-13], cell nucleus[14] and induce major structural damage to mitochondria[15,16], cause DNA mutation[17], and even result in cell death [18]. That's why many biogenic syntheses of nanomaterials are being explored using different organisms which offer a reliable, low-cost and environment-friendly alternative approach compared with classical chemical and/or physical methods[19,20].

Application of metal oxide NPs such as Alumina, silica, MgO [21], ZnO[22], TiO_2 [23], etc., CNT and silver[24] NPs have been reported improving physicochemical and other functional properties applied majorly though coating, sol-gel, plasma etc. [25] for broader range of application domains like wearable super capacitors [26]. Probably, Gang Sun and Dapeng Li should be credited to file the first patent related to NP dyeing of textiles on 22 Oct 2001, entitled "Dyeing textiles using NPs" which was granted on 23 May 2006 [27]. Later in 2007, they published related work [28]. Recently, some important applications to various textile fibers are being reported[29-31]. Goetz et.al. [32] studied migration of Ag- and TiO2 NPs from textiles into the artificial sweat under physical stress and developed an exposure Modeling. They found that dermal exposure to nano-objects and their aggregates and agglomerates (NOAA) from textiles can be considered comparably minor for TiO2NOAA, but not for AgNOAA. Froggett et al. [33] reviewed well with the perspective of existing research on the release of nanomaterials from solid nanocomposites. In Fact, Textiles with silver NPs application share the most commercialized applications among another nanomaterial despite recent concerns about product safety[34-39]. However, a limited research has been reported in studying the dyeing ability and fastness properties [40] with enhanced functional properties, wearer comfort (moisture management test and surface frictional properties) along with cytotoxicity test and MMT test. All these are crucial factors for colorist, wearers' comfort as well as the environmentalist. Here, we show the promising results of four types of NP such as TiO2, Carbon NP, Alumina and Silica with enhanced mechanical, fastness and moisture management properties. In addition, we studied their surface friction and roughness properties to compare comfortable feel to the wearer.

Recent studies on toxicological risks of commercial nano-engineered functional textile have shown concern risk levels on sweating and common wear and tear in textile incorporated majorly though coating, spinning or sol-gel methods [32]. In fact, the stability of nano-oxide particles in the medium is always challenging; being an inorganic compound and lacking functional groups to leverage upon textile materials directly[41]. Thus, in many finishing processes of the fabrics, cross- linkers, resins, adhesives, binder, etc. are applied together with NP oxides to embed on the surface of the fabrics at the cost of inferior touch feel and fastness[42,43]. Undoubtedly, they are more toxic and prone to release NPs under physical stress and sweat. Many surface modifications of textiles and stabilizing nanoparticles require several steps of preparation, functionalization, final treatment, drying, curing and so on but are non-durable. Specifically, they can release nano-particle easily on washing or common laundering and also sweating. The entire process is very time consuming, high cost and limits high-scale manufacturing production[44,45].

In our previous study, we demonstrated a novel and simple way of incorporating TiO_2 NP with reactive vinyl sulphone class dyeing of cotton that economically can be practiced to enhance significant and lasting improvement in strength, wear resistance, stiffness and UV protection [25]. The results from SEM, Raman, FTIR and UV-visible spectral analysis along with physical property tests confirmed the diffusion of nanoparticles in polymer matrixes.

In this present investigation, we studied the diffusion of NPs into the fiber polymer matrix via dyeing technique that could be much safer in terms of cytotoxicity levels, durable and easy to process to tailor desired functional attributes. We studied here the possibility of a simple and eco-friendly application technique via dyeing of vinyl sulphone based reactive dye with four kinds of NPs followed by their cytotoxicity test using cell line A431 and MTT test. Promising results of four types of NP such as TiO2, Carbon NP, Alumina and Silica by dyeing was achieved with enhanced mechanical property and moisture management properties. In addition, their surface roughness and frictional properties to compare comfortable feel to the wearer were analyzed. A fiber matrix firm embedded system most likely to be achieved by Vander Waals forces of attraction Vis a Vis fiber, NP and reactive dye that also forms the covalent bond with cellulosic fibres[25,46]. The overview of reactive dyeing mechanism of dye migration from solution to the fibre surface, adsorption, diffusion and fixation on cotton by covalent bond formation was studied.

Materials & Methods

Materials, NPs and dyeing: The cotton material used; dyeing technique followed has been described well by khandual et.al. [25]. The NPs and dyes used are of following specifications.

1. The nano-alumina with trade name AEROXIDE® Alu©; specific surface area (BET) of 100 m^2/g primary particle size of 13 nm, obtained from Evonik, Degussa

2. Nano-silica with trade name AEROSIL®300; specific surface area (BET) of 300 m^2/g primary particle size of 7 nm, obtained from Evonik, Degussa

3. TiO_2 NP: Titanium (IV) Oxide -nanopowder, 21nm particle size collected from Sigma-Aldrich, Mumbai

4. Carbon Nanotube (CNT), Prepared in the Lab by electric arc method, particle size 31nm

5. Dye: Reactive Remazol Ultra RGB orange supplied by Dyestar, Hong Kong 1% (Dye+ NP) means that the mixture contains 0.9 gm of the dye with 0.1 gm of NP in 100ml of dye stock solution and 50 gpl Gluaber's salt and 10gpl soda were taken for dyeing to be raised at 70 degree centigrade. The dyeing method was followed as per the reference [22] followed by a hot wash, cold was and soaping by non-ionic detergent. Ultrasonification was carried out at the initial stage for homogeneous mixer of dye and nano particle.

Scanning Electron Microscopy (SEM): The control and NP dyed samples were analysed with Environmental scanning electron microscope (EP-SEM) of Zeiss, Model EVO 60 for SEM images along with EDEX results; these were provided in supplementary file

Disk diffusion assay: Disk diffusion assay was conducted to check the antimicrobial capacity of the clothes embedded with NP and dye. S.enterititis and E.coli strain were chosen for the assay. For assay, overnight culture of the bacterial strain cultured in Luria bertini medium at 370C in a shaking incubator was subcultured for 4 hours till the attainment of 4.0 OD (600nm). The bacterial strain were spread plate in a 60mm petriplate contained with LB agar medium to obtain a lawn.2mm diameter of different clothes embedded with nanoparticles were placed on the lawn to observe the antibacterial effect.

Cell culture and toxicological assays : The human squamous epithelial cell line A431 was cultured in Dulbecco's Modified Eagle Medium (DMEM) medium supplemented with 10% Fetal bovine serum (FBS), 2 g/L sodium bicarbonate and 2 mM L-glutamine (complete medium), in 25 cm2 tissue culture flasks in a humidified incubator at 37°C supplied with 5% CO2 in air atmosphere. For the MTT assay experiments, A431 cells were seeded in the wells of flat-bottom 96 well plates at 5×104 cells per well in complete medium containing the fabrics impregnated with NPs. The non-impregnated cotton was taken as control. MTT was poured after 24h and 48 h exposure. Followed by the completion of exposure time, the formazen crystals formed by MTT was dissolved by Dimethyl sulfoxide (DMSO). The Viability of cells was calculated in the relevance of control (no NPs), taken as 100%. For the morphological changes and microscopic analysis, the depleted culture medium was aspirated on the day of the experiment and replaced with 100µl of DMEM medium. The treated cells were then incubated for 24 hr. After incubation cells were taken for the microscopic examination.

MTT (3-(4, 5-dimethylthiazole-2-yl)-2, 5-biphenyltetrazolium bromide) assay is a color based assay which determines the viability of cells by measuring the color intensity of dissolved formazen crystals as an index of cellular mitochondrial dehydrogenase activity [47]. We tested the effect of TiO2,SiO2, Alumina and CNT NPs on A431 cell lines by exposing the cells for 24h to the samples impregnated with 1%,2% and 3% impregnation of these NPs. MTT Cell Viability Assay Cell Survivability was determined by MTT assay, which is a colorimetric assay depicted by measuring the intensity of purple color of buffer

(11gm SDS in 50ml of 0.02M HCl and 50ml isopropanol) which dissolves the formazen crystals produced by the reduction of MTT. The absorbance was taken at 570nm in enzyme-linked immunosorbent assay (ELISA) plate reader (Epoch, Biotek, Germany). The amount of color product formed was proportional to the number of viable cells. Mean absorbance of Non-treated cells was taken as the reference value for calculating 100% cellular survivability [6].

Results and discussion

The cotton textiles were checked for their physical and biological properties after dyeing. Physical properties like mechanical strength, moisture management, light fastness, surface friction were analyzed. Biological properties like antibacterial activity and cytotoxicity was determined.

Mechanical Properties: Tensile strength test and elongation of the untreated and NP dyed fabric (warp way) was conducted by Digital Tensile Strength Tester, Globetex, Delhi and tabulated below (Table 1). The results have shown significant improvement in tensile strength with a nominal decrease in elongation. 1% silica dyed sample has shown highest (198.5%) increase in tensile strength followed by 2% silica and 2% CNT whereas a decrease in elongation is highest in the case of CNT 2% (5.31%). The graph was depicted in figure 2 and figure S1.The increased strength in case of silica can be attributed to the thermodynamic affinity of fibers form noncovalent interactions such as dipolar–dipolar and hydrogen bond, causing adhesion of silica nanoparticles and covalent bond between the cellulosic hydroxyl group and –Si–OH in silica particles[48-50]. Similar observations were found in case of other nanoparticles as shown in figure S2. The increased strength obviously attributed to the presence of nanoparticles in the core of the fiber matrix creating a strong physical bond; some may be due to the mechanical entrapment, aggregation, covalent and Vander Waals forces.

Moisture management test: The Moisture management tests were carried out in MMT, SDL Atlas. It has been found that significant variation in water penetration levels between controlled and treated sample. Figure 3 depicts the water location vs. time (120 seconds) of controlled sample and 2% CNT dyed sample. As shown in figure 4a and 4b, the overall moisture management rating found out to be excellent (5) in the case of 2% CNT dyed sample as compared to controlled sample with a rating between 2-3. The parameters obtained clrealy signified the results. Kim et.al. reported the development of Bio-inspired, Moisture-

Powered Hybrid Carbon Nanotube Yarn Muscles which can be actuated well by either changing relative humidity or water contact [51]. Wei Li et.al. [52] recently developed "A yarn-like switch-type humidity sensing material, fabricated by infiltrating hydrophilic water-swellable polyvinyl alcohol (PVA) into a multi-walled carbon nanotube (MWCNT) yarn. The humidity sensing material demonstrates excellent repeatability and stability, acceptable hysteresis and response time". CNTs are well known for tailoring moisture absorption properties of hybrid materials". In Figure 4(c). MMT test results for other Nano particles dyed with controlled sample at 2% shade are shown and the data was given in Table 3. The MMT Test results interpretation for control and nano dyed samples were shown in table no. 4 [53,54]. From the above figure and tables it is evident the MMT parameters are significantly varying with the NP application. These tailored properties and controlled absorption could be explored for wide application in agriculture, food processing waste water treatments etc. which has been reported by different application technics [55,56]. The enhanced moisturemanagement properties were seen in case of CNT and silicathan compaired to TiO_2 followed by Alumina. Recently more interesting scopes on fluroscence and photocatalysis by various nanosphres has been reported, those have potentials for textile applications [57-60].

Light fastness : Method- AATCC 16 test standard was used with Xenon arc lamp light fastness tester with the exposure time 20 AATCC fading units(AFU)(= 20 hours). From the rating it is observed that the fastness to light is satisfactory and close to the parent reactive dye; exposure of light do not get influenced by presence of NP in the fabric and on the other way there is least chances of any reaction or degradation of fabric treated all four kinds of NP. Interestingly, the same phenomenon was obtaining while dyed with same class of ultra RGB blue reactive dye. This can ensure a strong fibre-nano-dye interlinking existing hereby. One test result image has been given below in figure 5. Literatures have reported that the durability of functional textiles along with lightfastness can be enhanced by application of nanoparticle or their combination for cotton and polyester[61-65]. The results were present on the scale of their fastness ranging from 0-10. Here we achieved good results i.e. a level of 5-6 as compared to the parent dye level of 4-5 (Figure 5). The light fastness of the samples either similar or enhanced to higher level when nano particle is applied along with base dyes.

Surface friction and variation: Surface friction and variation were also studied in Kawabata's evaluation system FB-4, where MIU (Coefficient of friction), MMD (Mean deviation of MIU) and SMD (Geometrical roughness) (Table 2). The results have shown that the surface friction and roughness have been decreased in case of NP dyed samples. The observed result can be attributed to the diffusion of NPsin to the textile matrix so observed in SEM and EDS results. However, TiO_2 2% and CNT3% NP dyed samples are much closer to controlled one. Silica NP dyed samples have shown a drastic reduction in surface friction and roughness characteristic of the samples followed by alumina [61].

Antimicrobial analysis: Nanoparticles have been shown to exhibit antimicrobial properties [66,67]. However, it is interesting to understand their antimicrobial behavior when embedded with textiles in order to understand their effect on their wearable properties. We have checked the antibacterial effect of clothes embedded with NPs with dye with two different bacterial strains (*S. typhii* and *E.coli*) to evaluate the effect of clothes on bacteria. As shown in figure 6 and figure S3, No inhibition zone was observed in control experiments and in the experimental set of clothes dyed with 1% and 3% NPs. The strange behavior can be attributed to the fact that the concentration of NP is too low to be diffused from the clothes. The NPs were attached to the fibers of the clothes firmly as interpreted from our physical analysis hence, were unable to get diffused showing no inhibition zone with bacteria. The exhibited properties can be considered beneficial with respect to the beneficial bacteria present at the skin.

Cytotoxicity Test: Dermatological effects of NPs are questioned whether they are able to penetrate into or through the skin! Logically, if superficially bound NPs are present in the surface of the textile, it may cause more risk. *In vitro* studies reported that multi-walled carbon nanotubes are capable of localizing within and initiating an irritation response in human epidermal keratinocytes, those are responsible for occupational exposure [32]. Similarly, it is well known that in order to avoid photo-oxidation of many metal oxides, commonly TiO_2 Silica is also used to act as protective adhesive [68]. However, the cytotoxic effect of the fabrics impregnated with these NPs is still not understood clearly! To address these facts, we applied four kinds of NPs with dye at various concentration levels; 1%, 2% and 3% to the fabrics and studied their change in morphology and subsequently their effect on the viability of skin cell lines. It was found that the cell line A431 were almost alive or found to be infected with morphological changes in between 1-2% range after 48 hours (Fig. 6-10). We can notice that silica at 2% level even harms Cell lines A431. As shown in figure

7, it was clearly observed that the viability of cells has depended on nature and percentage impregnation of NPs. It was observed that the viability was least in 3% in comparison to 1% and 2%. The A431 cells were showing their survivability in order TiO_2> CNT> Alumina> Silica at all impregnation concentration. This observation was well supported by the bright field imaging of these cells when exposed to the corresponding samples (Figure 7). Although alternative processes of nano application to textiles prevailing currently, they use much higher concentration levels of NPs that has to be paid much attention in terms of cytotoxicity; these processes involve lots of toxic material, organic solvents in several stages [25,69]. The MTT assay results (Figure 8) supported the morphological analysis where the cell viability was found decreased to 43%, 86%, 55%, and 62% at 3% impregnation of Silica NP, TiO_2 NP, Alumina NP and CNT respectively. It has been found that the degree was in order TiO2>CNT>Alumina>Silica. Moreover, the viability of the cells was decrease by 10% at lower percentage of NP. The results depicted that cytotoxicity of the NP dyed textile varies with the nature and concentration of the NP. It is a matter of concern that silicone/ polysiloxane are being extensively used for various functional finishes such as softeners, binder cross linkers etc [70] , it has been observed from the MMT test that it is harmful even at very low concentration level.

It can be expected well to tailor various functional properties by applying NPs, but limited to be discussed here. Some of the SEM results has been provided as supplement material that confirms gradual diffusion and fixation of dyes into the textile polymer matrix of the textile substrate and in these cases, it reduces the chances of exposed NPs on the surface of the textile fibres.

Conclusion

In this novel study, we used four types of NP having average particle size ranging from 13nm to 31 nm such as TiO2, Carbon NP, Alumina and Silica via simple dyeing of vinyl sulphone based reactive dye assisted by prior ultrasonic agitation at low concentrations i.e. 0.05gm of nano particle with0.95gm dye for dyeing 100gm fabric for 1% shade. The diffusion of NPs into the fiber polymer matrix via dyeing technique could be much safer in terms of cytotoxicity levels, durability and ease of application to tailor desired functional attributes. Promising results were achieved in terms of enhanced mechanical property and moisture management properties. In addition, their surface roughness and frictional properties were analysed to compare comfortable feel to the wearer. This will drastically lower the probability of NP release as they diffused predominantly to core, not in the surface, evidenced by significant improvement in mechanical properties. Safer application at lower level of concentrations were tested by cytotoxicity test using cell line A431 and MTT test .Interestingly, it has been found that it is possible to incorporate these NPs in an effective manner at 1-2% shade range range rather than higher concentration of 3%, to reduce cytotoxicity risk level with enhanced strength, moisture management and improved surface feel.

As discussed earlier, the stability of nanoparticles in the medium is always challenging, being an inorganic compound and lacking functional groups to leverage upon textile materials directly. Thus, in many finishing processes of the fabrics, cross-linkers, resins, adhesives, binder, etc. are applied together with NP oxides to embed on the surface of the fabrics at the cost of inferior touch feel and fastness. Undoubtedly, they are more toxic and prone to release NPs under physical stress and sweat. The SEM with EDS results provided as the supplementary documents corroborate this fact that the optimum level of application ensures most of the NPs may be present on the core of the fiber. Most probably, therefore, previously NP treated fabrics are not recommended to be worn directly onto the skin or their toxicity tests have not been well reported. Keeping it in mind, we could be much safer in making the best use of low concentration NPs in dyeing textile for developing many functional properties of textiles to improve mechanical performances, UV protection, flame resistance and so on.

Conflicts of interest

There are no conflicts to declare.

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Figures and tables:

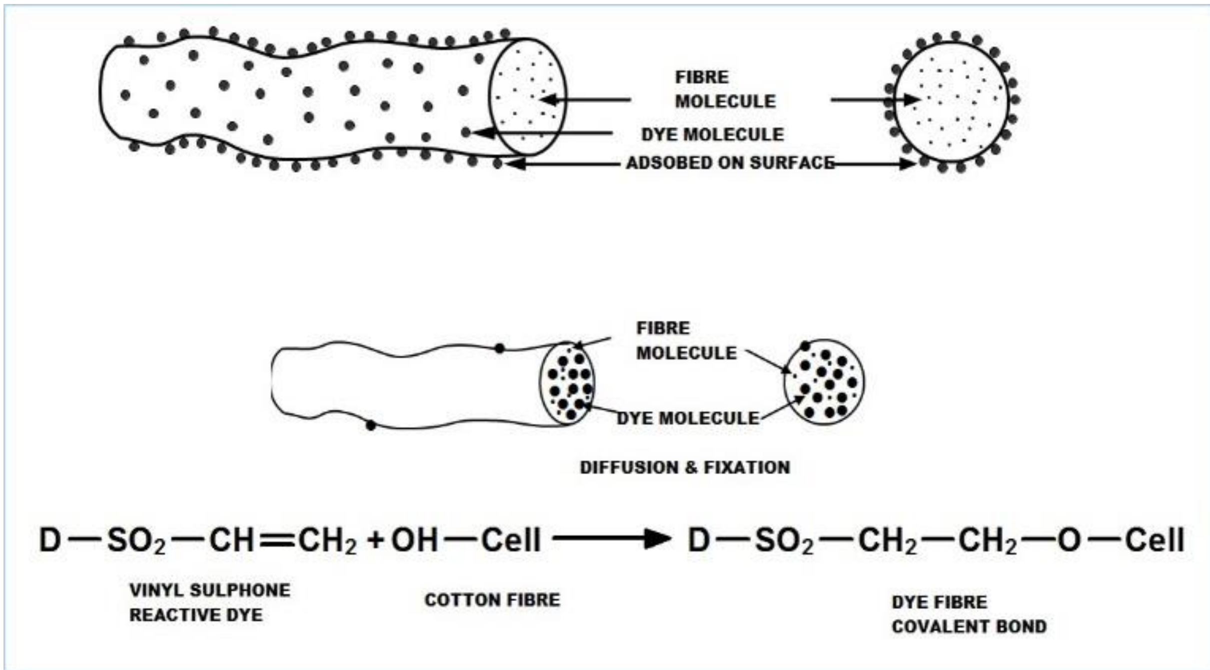
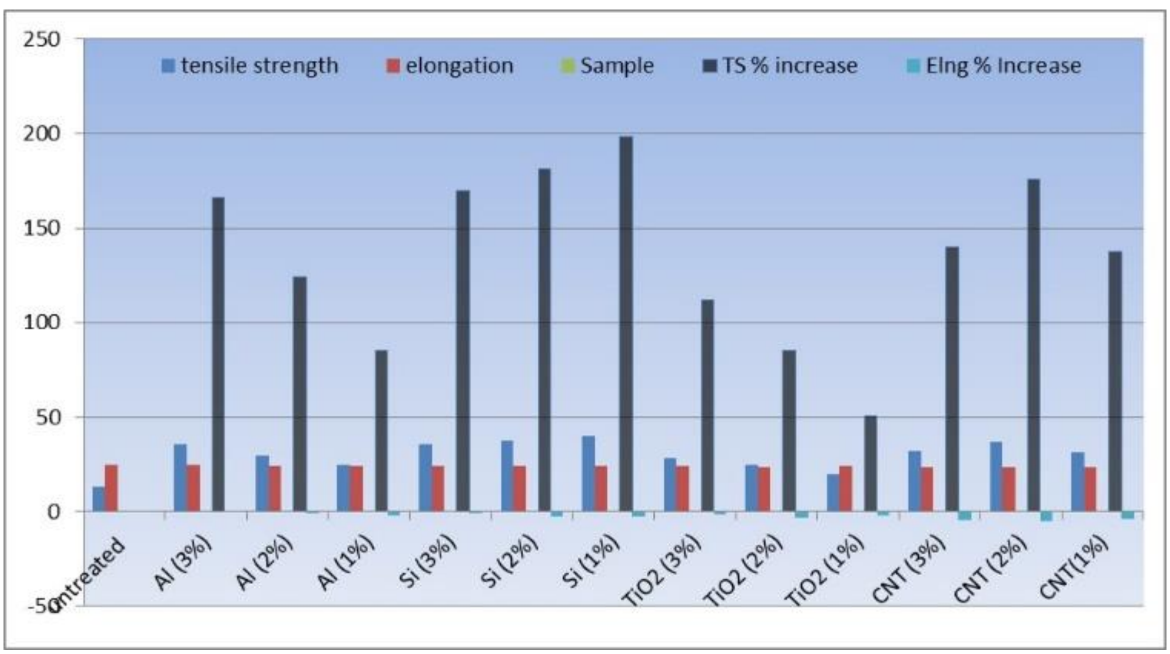


Figure 1: Reactive dyeing system on Cotton



[Figure 2. Tensile strength and elongation of control and NP dyed samples]

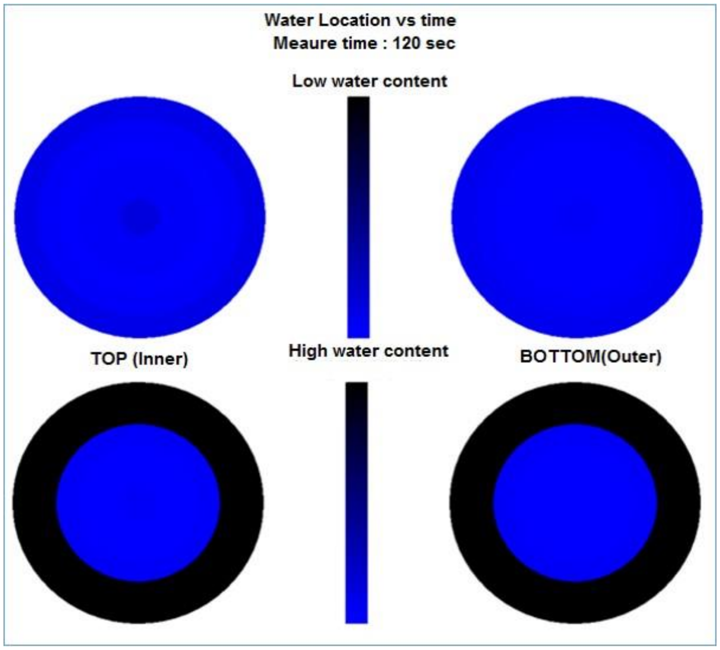


Figure 3. MMT test: Water location vs. time; Lower: controlled sample, Upper: 2% CNT

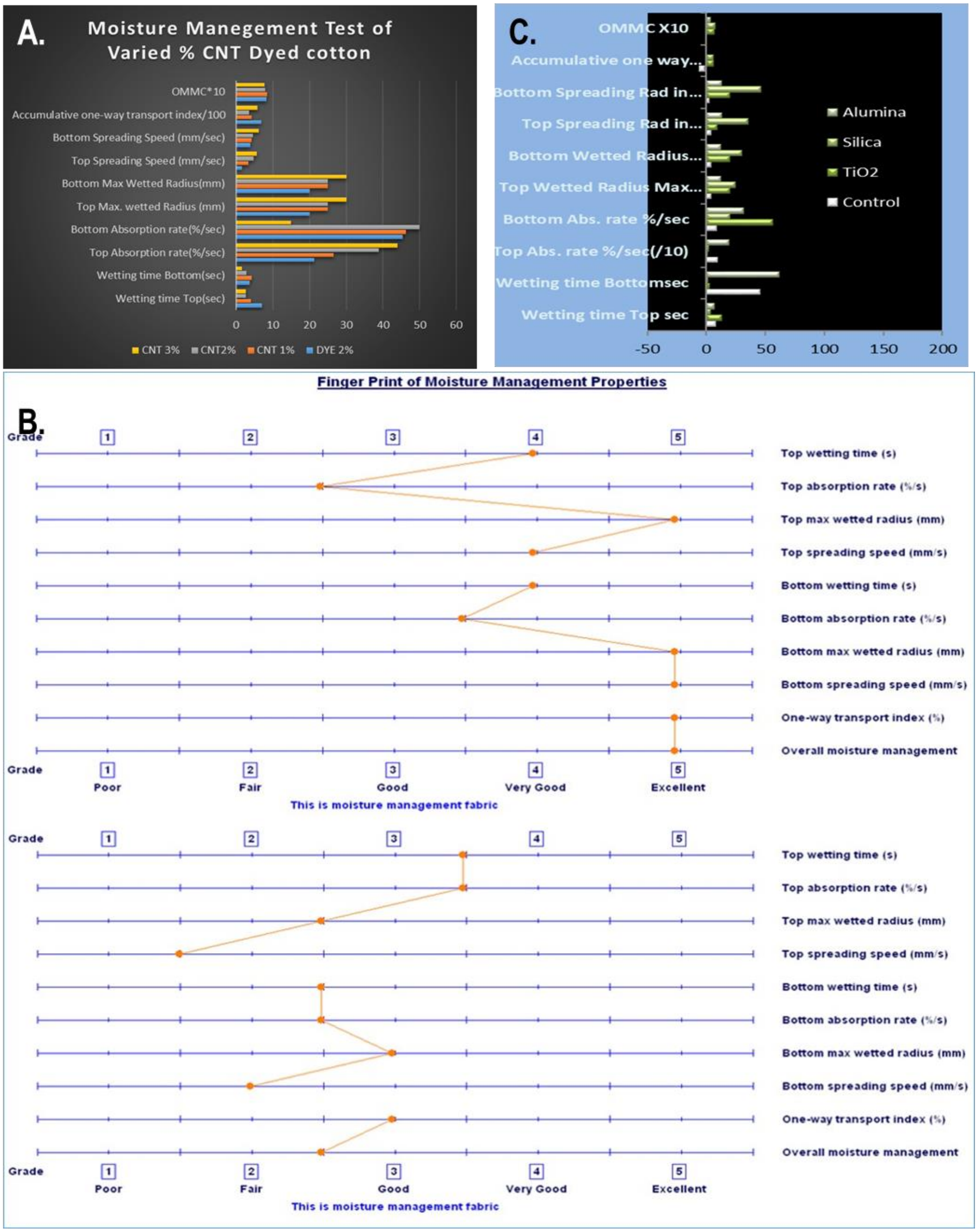


Figure 4: (A) Influence on CNT % on MMT Properties (B) MMT test for overall rating; Lower: controlled sample, Upper: 2% CNT (C) MMT test for other Nano particles dyed with controlled sample at 2% shade.

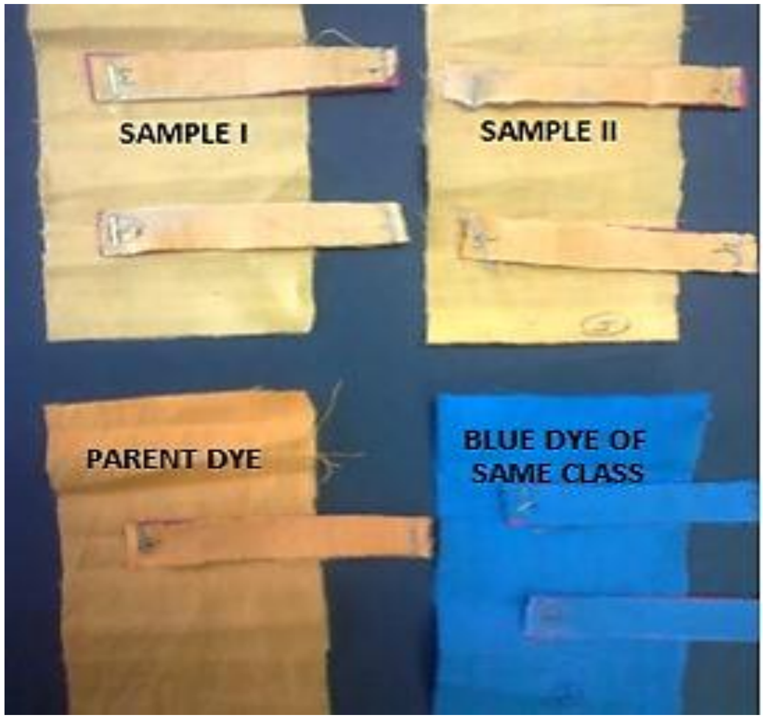


Figure 5: Light Fastness Test of the textile dyed with different nanoparticles. Sample I and Sample II present different textiles compared with the parental dye.

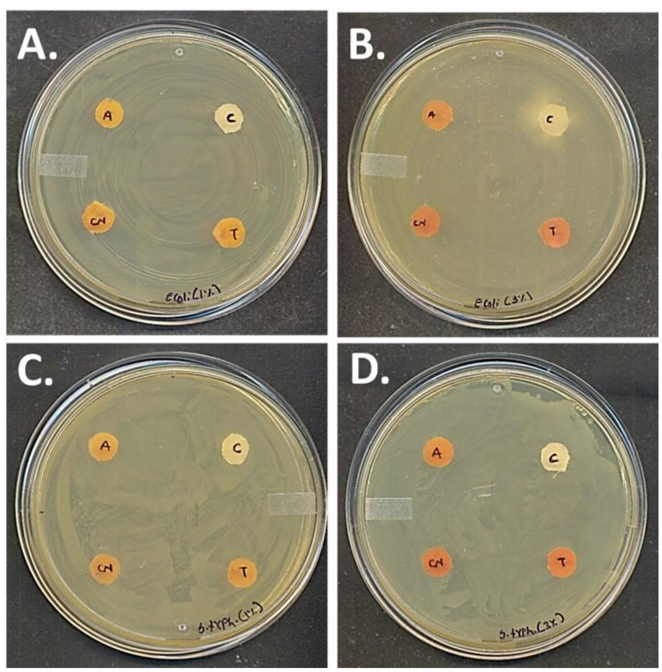


Figure 6: Antibacterial activity of clothes embedded with NPS and dye. "A" presents Alumina, "C" presents Silica, "CN" presents CNT and "T" presents TiO_2 NP.

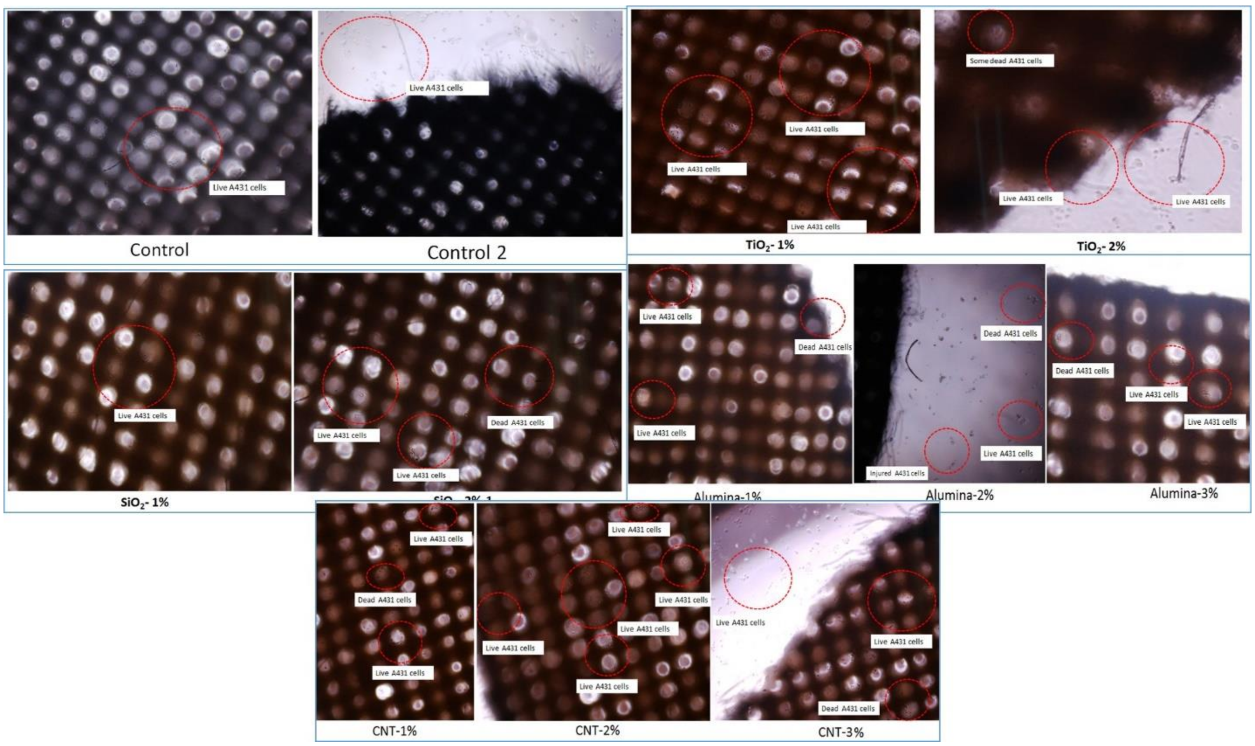


Figure 7: Morphology of the cells accompanied with samples dyed with silica, TiO_2, Alumina, and CNT NPs 1% & 2%.

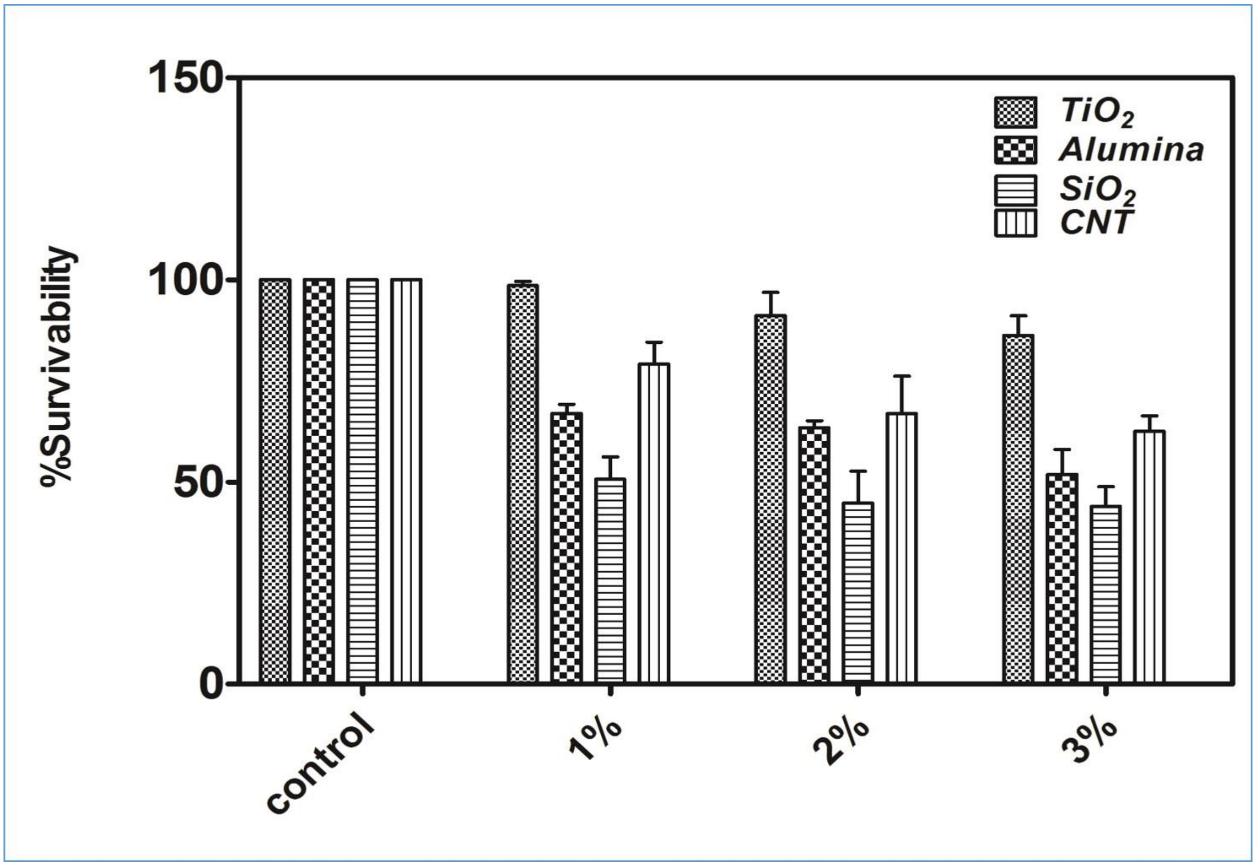


Figure 8: Survivability analysis of A431 cells with samples dyed with different NPs.

Table 1. Tensile strength and elongation of control and NP dyed samples

Sample	tensile strength(Kgf)	Elongation(mm)		TS % increase	Elongation % Increase
untreated	13.3	24.5		0.00	0.00
Alumina (3%)	35.4	24.5		166.17	0.00
Alumina (2%)	29.8	24.3		124.06	-0.82
Alumina (1%)	24.6	24		84.96	-2.04
Silica (3%)	35.9	24.3		169.92	-0.82
Silica (2%)	37.4	23.9		181.20	-2.45
Silica (1%)	39.7	23.8		198.50	-2.86
TiO_2 (3%)	28.2	24.2		112.03	-1.22
TiO_2 (2%)	24.6	23.7		84.96	-3.27
TiO_2 (1%)	20	24		50.38	-2.04
CNT (3%)	31.9	23.4		139.85	-4.49
CNT (2%)	36.7	23.2		175.94	-5.31
CNT(1%)	31.6	23.5		137.59	-4.08

Table 2. Kawabata's evaluation system FB-4 reading of samples for surface friction and roughness

samples	Weft			Warp		
	MIU	MMD	SMD	MIU	MMD	SMD
Dye 1%	0.205	0.0169	4.27	0.193	0.0228	4.835
Alumina 3%	0.168	0.0225	7.19	0.191	0.0159	4.69
Alumina 2%	0.176	0.0173	7.355	0.193	0.0222	4.16
Alumina 1%	0.173	0.011	5.81	0.192	0.0260	4.745
Silica 3%	0.153	0.0089	3.92	0.168	0.0225	7.19
Silica 2%	0.15	0.0077	4.715	0.156	0.0201	6.33
Silica 1%	0.153	0.0095	4.34	0.154	0.0211	6.735
TiO2 1%	0.187	0.0142	3.125	0189	0.0192	4.99
TiO2 2%	0.192	0.0145	3.17	0.198	0.0175	4.41
TiO2 3%	0.199	0.0215	3.22	1.88	1.57	4.88
CNT 3%	0.188	0.0134	3.57	1.94	0.88	3.355
CNT 2%	0.189	0.0215	3.22	1.88	2.16	7.235
CNT 1%	0.197	0.0187	2.955	1.87	2.55	4.38

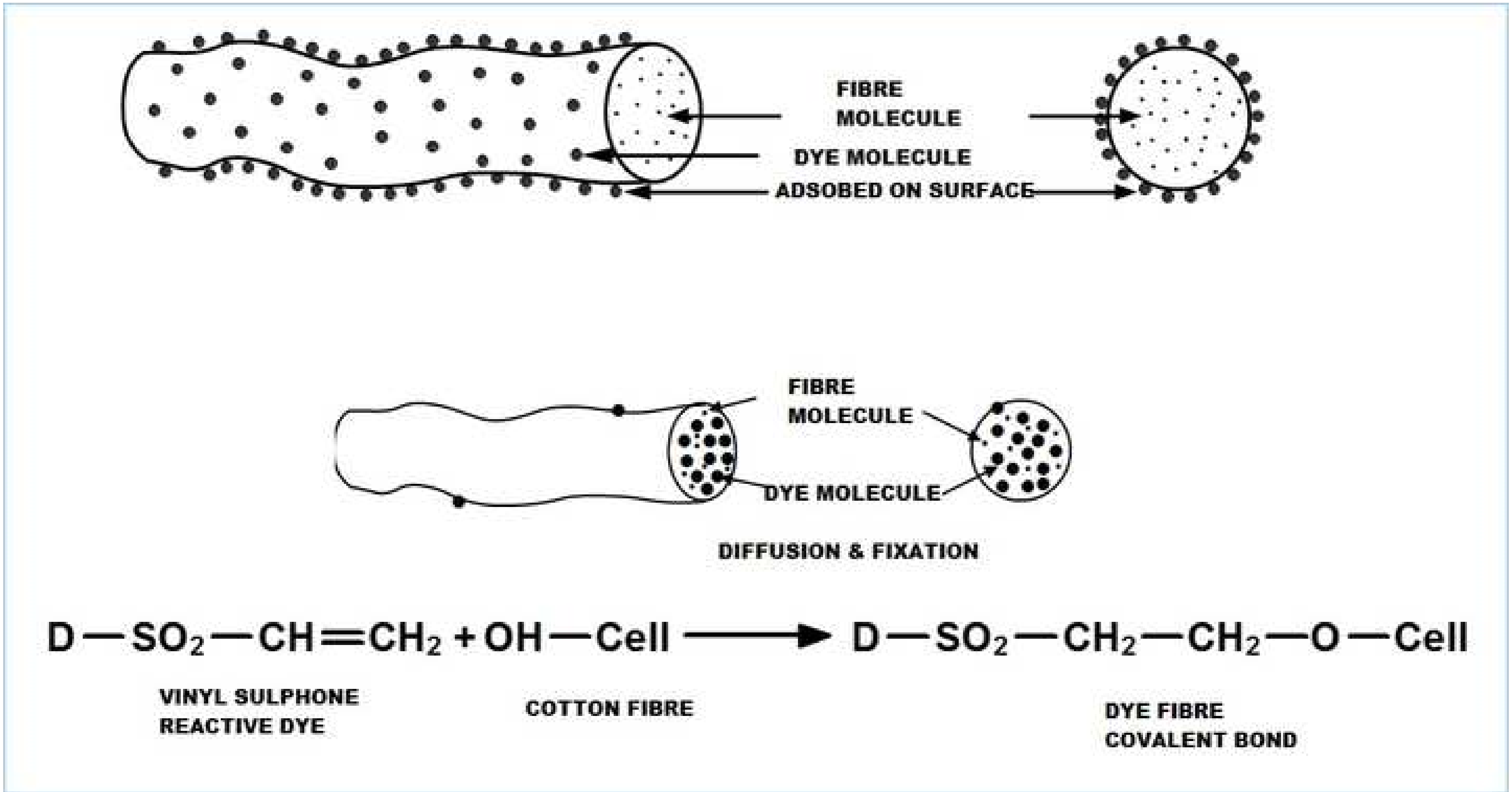
Table 3. MMT Test Results for control and nano dyed samples

Moisture Management Test	Control Fabric	TiO2	Silica	Alumina	CNT
Wetting time Top(sec)	9.125	13.406	4.203	7.2815	2.672
Wetting time Bottom(sec)	45.9637	3.078	1.875	61.875	2.843
Top Absorption rate(%/sec)	103.7727	13.731	24.83	192.0076	38.8708
Bottom Absorption rate(%/sec)	9.4168	56.4955	20.1684	31.4327	49.9674
Top Max. wetted Radius (mm)	5	20	25	12.5	25
Bottom Max Wetted Radius(mm)	5	20	30	12.5	25
Top Spreading Speed (mm/sec)	0.5421	0.97	3.5275	1.3535	4.7351
Bottom Spreading Speed (mm/sec)	0.387	1.9801	4.6258	1.3122	4.4666
Accumulative one-way transport index	-543.6364	658.5499	605.1055	-83.9725	340.4473
OMMC	0.0091	0.7108	0.7782	0.3911	0.7949

Table 4. MMT Test Results interpretation for control and nano dyed samples

Moisture Management Test	Control Fabric	TiO2	Silica	Alumina	CNT
Wetting time Top(sec)	mediu m	medium	Fast	medium	very fast
Wetting time Bottom(sec)	slow	fast	Very Fast	slow	very fast
Top Absorption rate(%/sec)	Very fast	slow	Slow	Very fast	medium
Bottom Absorption rate(%/sec)	very slow	fast	slow	Medium	medim-fast
Top Max. wetted Radius (mm)	No Wetting	Large	Very Large	Medium	very Large
Bottom Max Wetted Radius(mm)	No Wetting	Large	Very Large	medium	Very Large
Top Spreading Speed (mm/sec)	very slow	Very Slow	Fast	Slow	very fast
Bottom Spreading Speed (mm/sec)	very slow	Slow	Very Fast	slow	very fast
Accumulative one-way transport index	poor	excellent	excellent	Poor	very good

OMMC	poor	Very Good	Very Good	Fair	very good/Excellent


FIBRE
MOLECULE
DYE MOLECULE
ADSOBED ON SURFACE
FIBRE
MOLECULE
DYE MOLECULE
DIFFUSION & FIXATION
D—SO2—CH=CH2 + OH—Cell ⟶ D—SO2—CH2—CH2—O—Cell
VINYL SULPHONE
REACTIVE DYE
COTTON FIBRE
DYE FIBRE
COVALENT BOND

Figure

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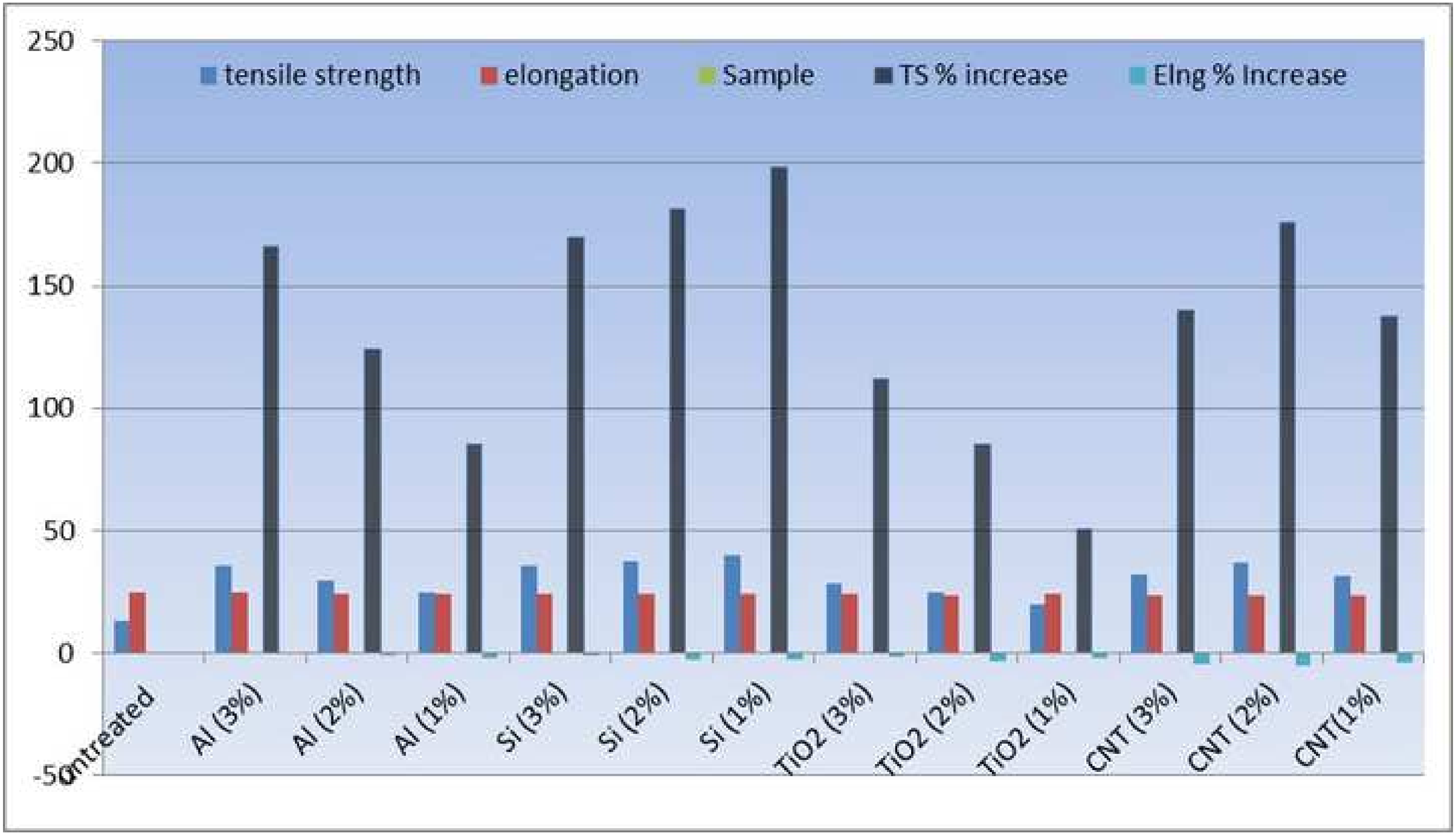

Figure

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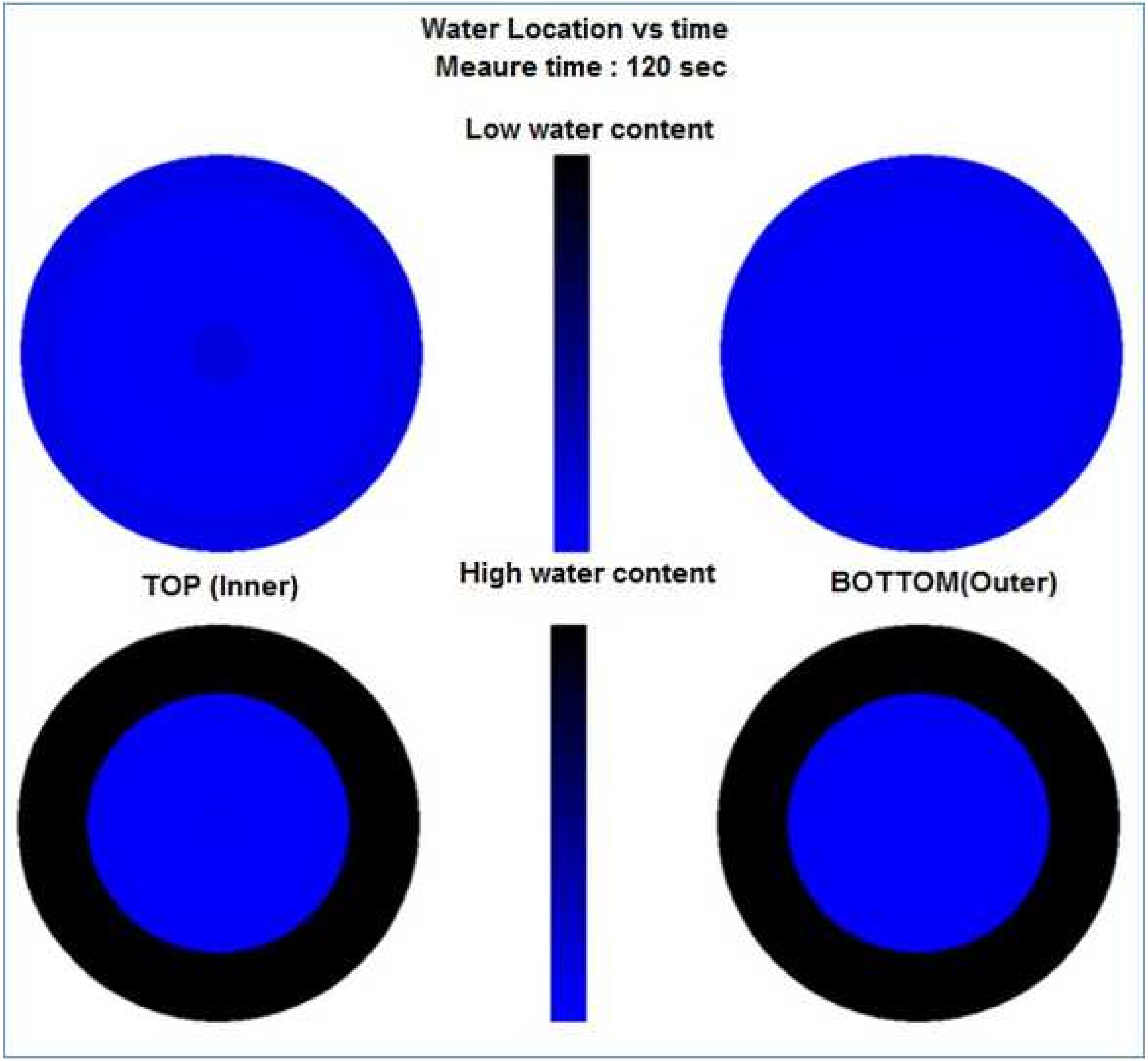

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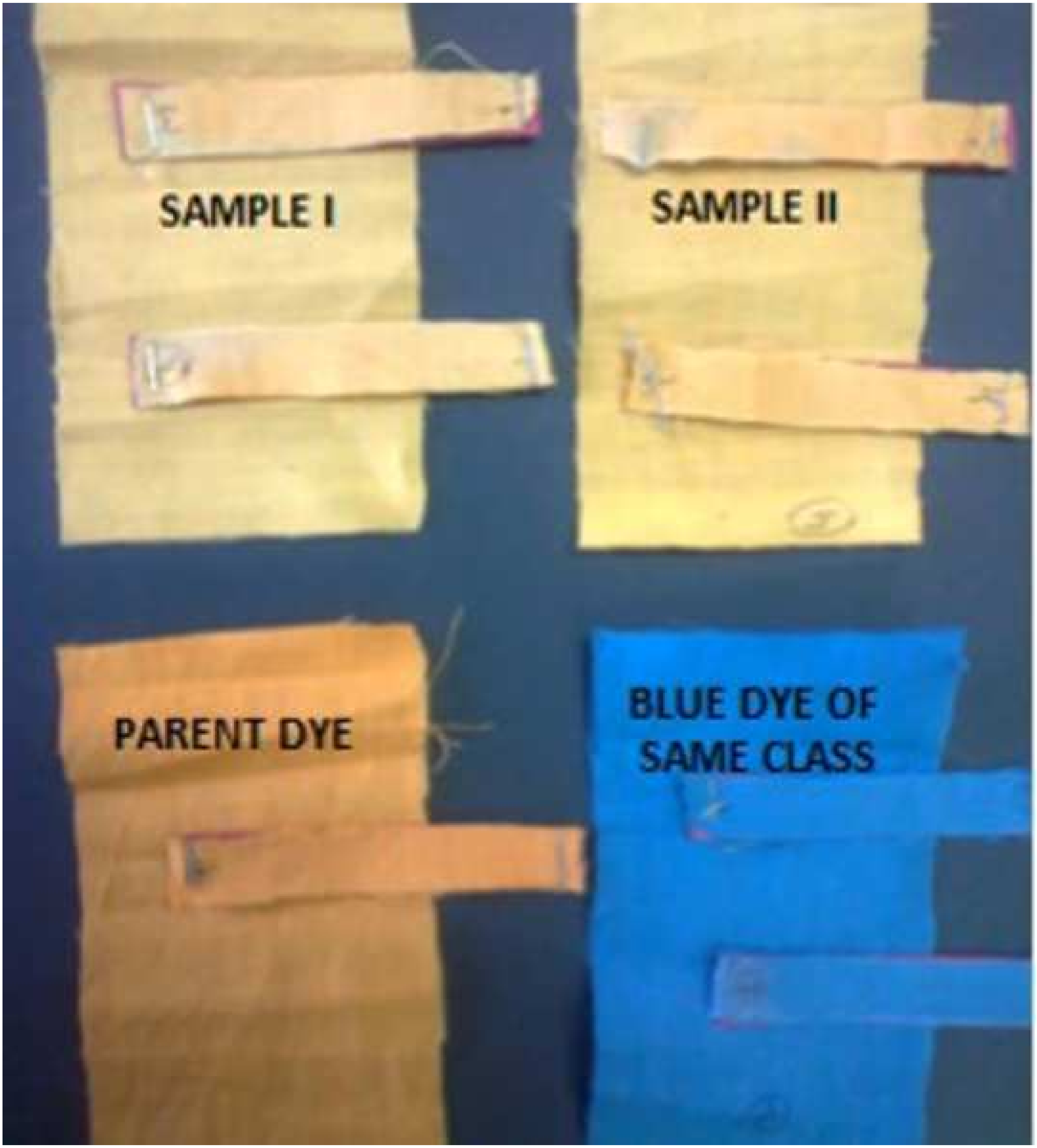

Figure

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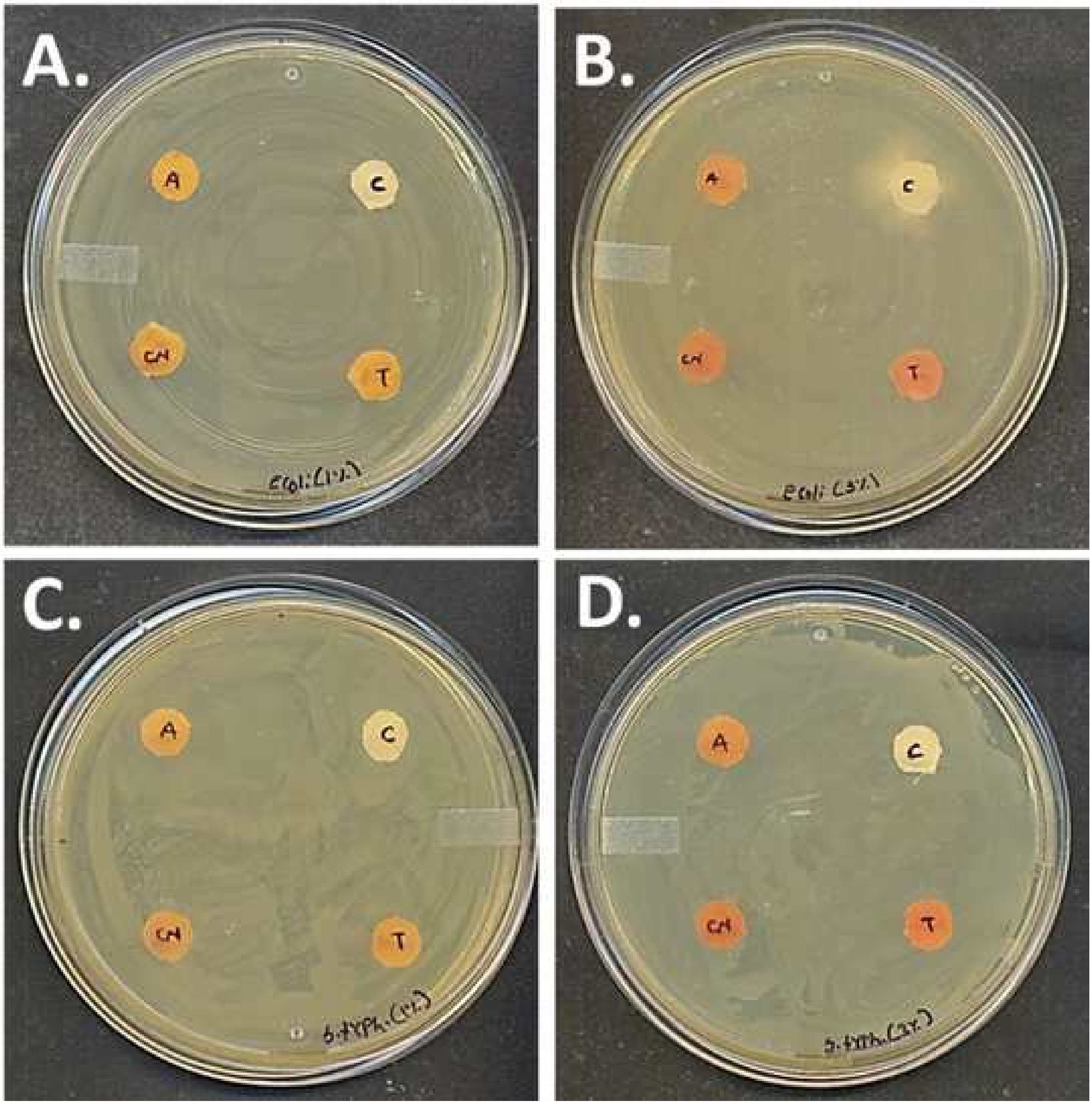
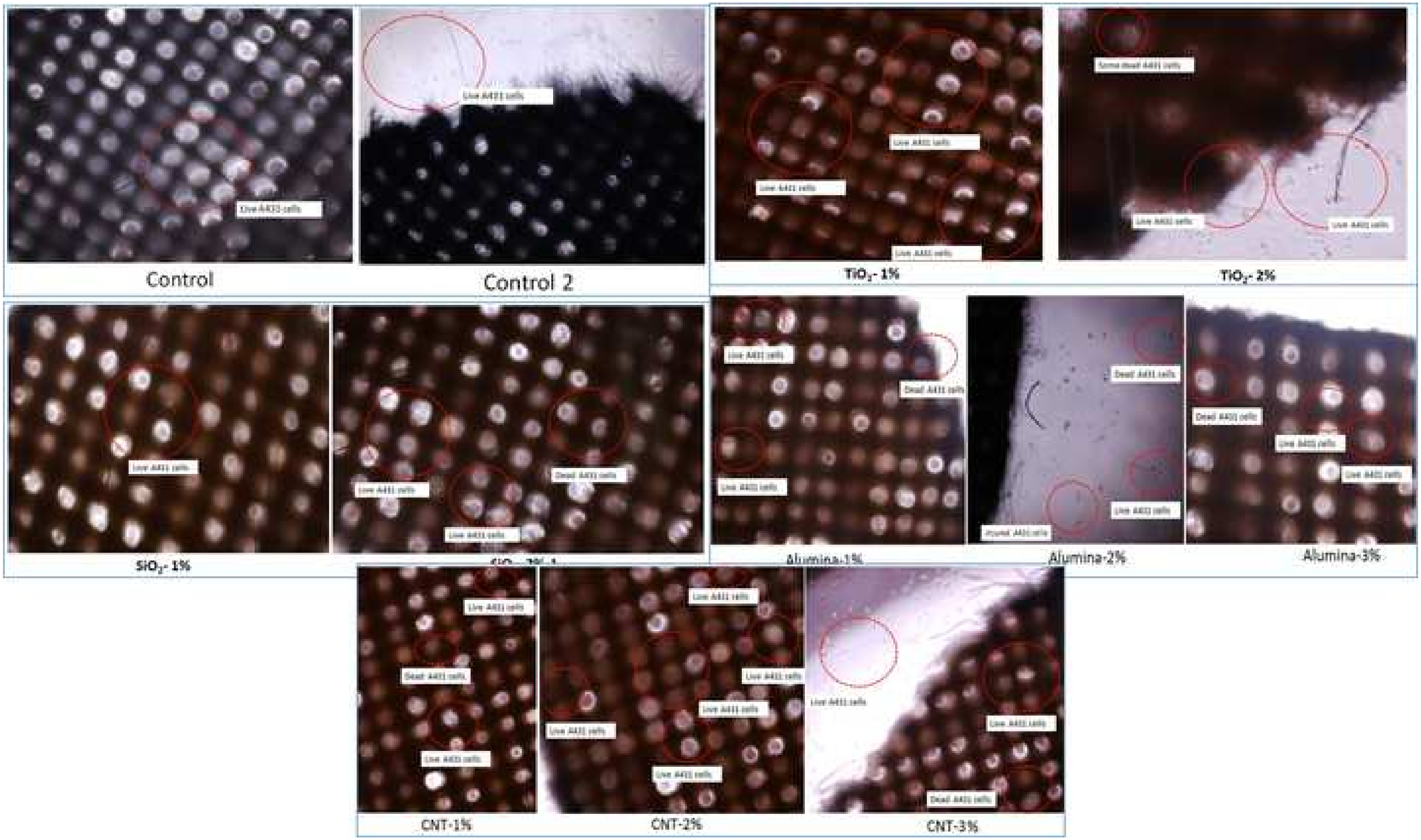
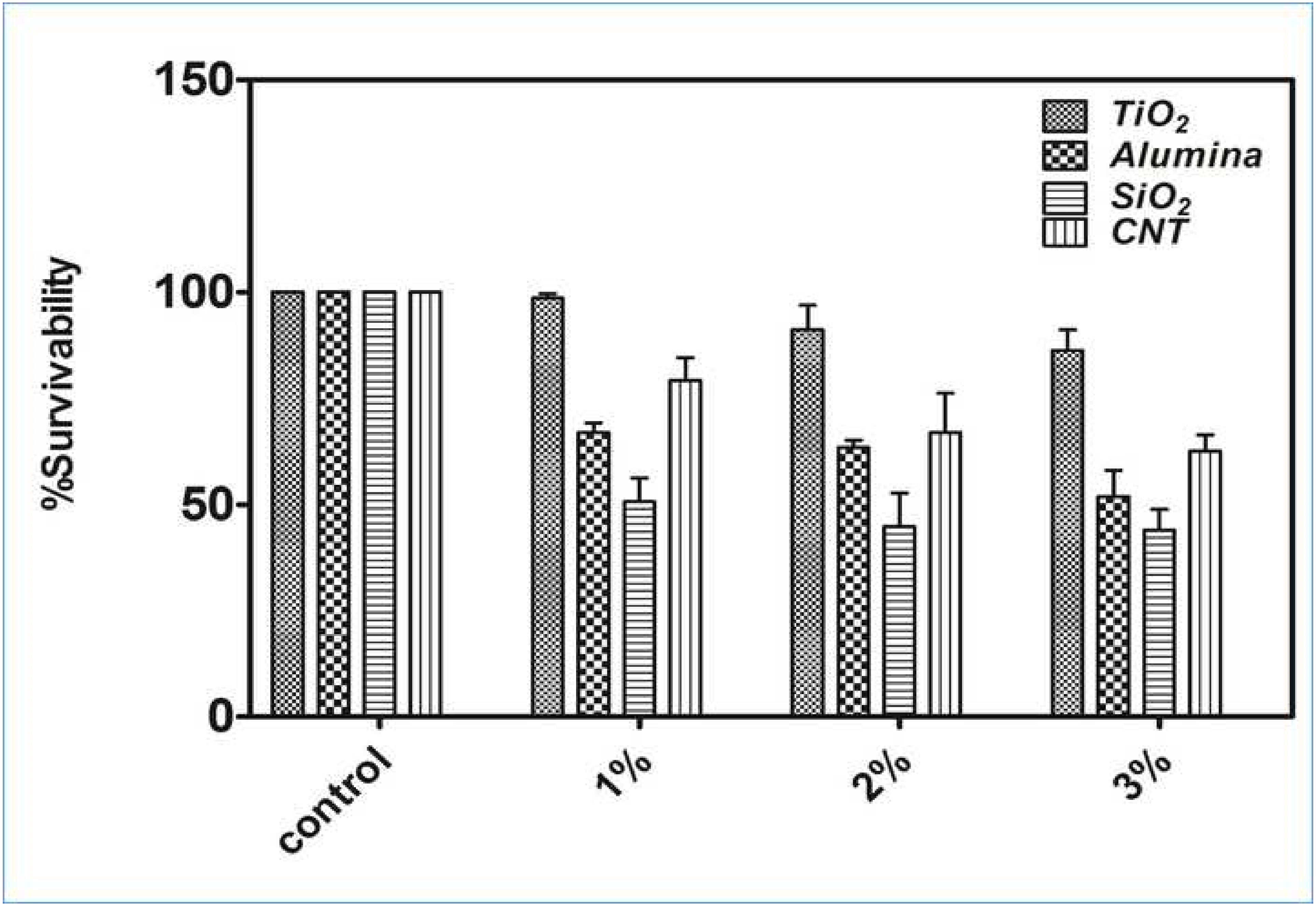
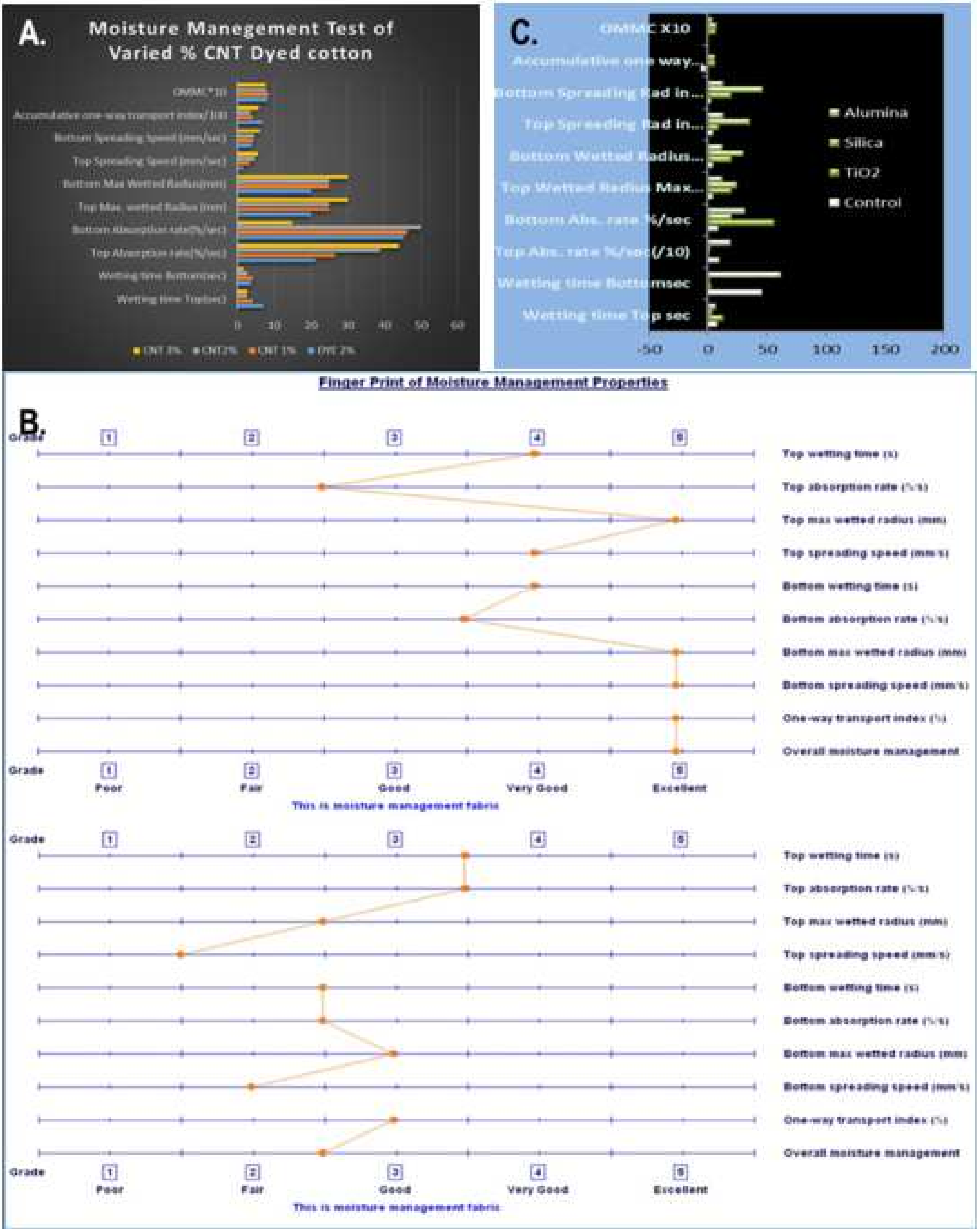


Figure

[Click here to access/download;Figure;Figure 7.jpg]




150
100
50
0
%Survivability
TiO2
Alumina
SiO2
CNT
control
1%
2%
3%


A.
Moisture Manegement Test of Varied % CNT Dyed cotton
CNT 3%
CNT2%
CNT 1%
DYE 2%
C.
OMMC X10
Accumulative one way...
Bottom Spreading Rad in...
Top Spreading Rad in...
Bottom Wetted Radius...
Top Wetted Radius Max...
Bottom Abs. rate %/sec
Top Abs. rate %/sec(/10)
Wetting time Bottomsec
Wetting time Top sec
Alumina
Silica
TiO2
Control
-50
0
50
100
150
200
Finger Print of Moisture Management Properties
B.
Grade
Top wetting time (s)
Top absorption rate (%/s)
Top max wetted radius (mm)
Top spreading speed (mm/s)
Bottom wetting time (s)
Bottom absorption rate (%/s)
Bottom max wetted radius (mm)
Bottom spreading speed (mm/s)
One-way transport index (%)
Overall moisture management
Poor
Fair
Good
Very Good
Excellent
This is moisture management fabric