Investigation of Acrylic Resin Treatment and Evaluation of Cationic Additive Quality Impact on the Mechanical Properties of Finished Cotton Fabric

Nasr Litim, Ayda Baffoun

Abstract: Statistical design of experiment (DOE) is an important tool to improve and developed of existing products or processes. This paper investigates the effect of essential finishing factors; curing temperature, curing time, resin, catalyst and cationic additive concentrations on the mechanical properties, especially on 3D ranks of cotton treated fabric with a copolymer acrylic resin. After that, it evaluates the impact of cationic additive class on 3D ranks and mechanical properties loss (breaking strength, breaking elongation and tear strength) of treated fabric with acrylic resin. The results, showed that cationic type effect; firstly (Electroprep) has the best quality on 3D rank of treated fabric and effect a little loss on mechanical properties, secondly (Easy stone super X), whereas (Easystone K) lead to a negatively loss on mechanical properties and gives undesired 3D rank. In order to investigate the causes of resin finish resumption and downgrading of garments in textile industry caused by ingredient concentration in bath resin. The main effect plot, interaction plot and contour plot method applied give to the textile engineer the possibility to predict the effect of resin treatment factors on the final quality desired of 3D rank and preserving the mechanical characteristics of treated fabric.

Keywords - Mechanical properties, Cotton, Resin, 3D ranks, Cationic

I. INTRODUCTION

In Textile processes, it is often of primary interest to develop the relationships between the key process variables and the performance characteristics. Mathematical modelling play an important role in developing, analyzing and predicting the relationship from experiments with certain level of confidence [1-2].When several variables influence a certain characteristic of a product, the best strategy is then to design an experiment (DOE) so that objective conclusions can be drawn rather than critical. In the context of DOE in Textile two types of process variables: qualitative and quantitative factors [3-4]. In this way, modeling and optimization the acrylic resin treatment of treated denim fabric using DOE. At present, for the three dimensional effects, DMDHEU crosslinker and its derivatives self catalyzed or not in mixture with other products, for example catalysts, acrylic cross linkers, Acrylo styrene emulsion are today supplied to textile industry. The method used for 3D rank (or effects) in cellulosic textiles is to apply a cross linking agent that reacts with hydroxyl groups of cellulose in the presence of heat and catalysts to form covalent cross-links between adjacent cellulose molecular chains. Fibers, yarns and fabrics treated exhibited increased resilience [5, 6]. Catalyst types, the amount of catalyst, or the temperature and time of curing are factors that can be varied to assist them in improving their reactivity. Conversely, reactants that have a high reactivity have less need for a strong catalyst and/or high temperature and long time curing than do low reactivity reactants. Temperature and time of curing not only affect the rate of reaction but also affect yellowing of cellulosic fabrics. Excessive temperature and time of curing may burn cellulosic fabrics and affect them to yellow. A temperature of 180 °C is normally used as the curing temperature for formaldehyde-free durable. The presence of adequate catalysts in the application of durable press chemical finishes is one factor affecting the performance of fabrics. Reactants used for durable press finishes do not have their reactivity at the same level. Some reactants have low reactivity, which means they can react with cellulose at a low rate of reaction [9].

The aim of this paper is to investigate a copolymer acrylic resin “Resacryl BD” treatment, additives characteristics and curing conditions (curing temperature and time) on mechanical properties of cotton fabrics. Afterward, it evaluates the impact of cationic additive quality on 3D ranks of treated cotton fabric.

II. MATERIALS AND METHOD

In this experimental study, we choose only a 100% cotton denim fabric among the most used in industry. More details gives in Table 1.

Table 1 Fabric Characteristics

Characteristic	Value
Warp Nm	14,75
Weft Nm	12
Density	29/15
Weight (g/m3)	410,69
Breaking strength warp (N)	418,16
Breaking strength weft (N)	314,16
Breaking elongation warp (mm)	29,05
Breaking elongation weft (mm)	16,72

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Tear strength warp (N)	41,61
Tear strength weft (N)	32,97

A. *Finishing process*

Firstly, we prepare the bath solution to impregnation with defined combinations. It contains resin or crosslinking agent and other additives to improve the crosslinking. The full chemical products are from "PROCHIMIC". For each resin solution, we measured pH at room temperature. We determinated the add-on of treated fabric, before impregnation of samples in the bath containing resin solution at ambient temperature 25 ° C for 5 minutes. Fabric to liquor ratio used was 1:10. After resin application, the treated sample is fixed on a special bracket, where fashioned 3D rank on different place in fabric. The treated sample underwent a predrying oven at 100 ° C for 20 minutes in a machine called 'Margherita', before the crosslinking that's considered important steps. Crosslinking is realized with two factors that greatly influence the quality of the results, which are the curing time and the curing temperature in a hot air oven. This thermal equipment is designed to heat air at moderate temperatures. After resin treatment, the treated fabrics were desized with amylase product 2 $g.l^{-1}$and softened with "CHTTACC" 1 $g.l^{-1}$ for 10 min at 50°C, washed with enzyme "Novasi ultra MC/M" 2$g.l^{-1}$ for 15 min at 40°C, Finally, the treated samples are dried for 20 min at 90°C and conditioned. In order to facilities the discussion, it use the abbreviation of used variables presented in Table 2.

Table 2 Abbreviation Parameters of DOE

Product / Properties	Code	Function	Unit
Curing temperature (°C)	X1	Physical Properties	°C
Curing time (min)	X2	Physical Properties	minutes
Resacryl BD concentration	X3	Acrylic resin finish	$g.l^{-1}$
Catalyst PAZ concentration	X4	Catalyst	$g.l^{-1}$
Acetic Acid AA concentration	X5	Additive	$g.l^{-1}$
Easy stone super X concentration	X6	Cationic additive	$g.l^{-1}$
Breaking Strength in warp direction (N)	Y1	Mechanical Properties	N
Breaking Strength in weft direction (N)	Y2	Mechanical Properties	N
Breaking elongation in warp direction (%)	Y3	Mechanical Properties	%
Breaking elongation in weft direction (%)	Y4	Mechanical Properties	%
Tear Strength in warp direction (N)	Y5	Mechanical Properties	N
Tear Strength in weft direction (N)	Y6	Mechanical Properties	N
3D rank	Y7	Properties	**
3D Thickness (mm)	3DTh	Properties	mm
Dry crease recovery angle	DCRA	Properties	Degree°

In experimental, it applied a full factory design to achieves a resin treatment process (64 = 2^6). For details, it use 6 factors with 2 levels presented in Table 3. Levels of DOE are chosen referring to the technical manual product.

Table 3 Design of Experiments DOE (full factorial design 2^6)

Level	DOE Factors					
	X1	X2	X3	X4	X5	X6
1	90	10	50	5	2	6
2	120	40	200	20	6	30

The main effects plot will be investigated. The main effects plot represents the average of the answers for every level of every parameter with the tracing of a reference line of the global average of the answer information. This diagram is essentially used to compare the importance of the main effects of the different parameters [7]. Previously, the 3D ranks were evaluated by fastness to wash, the maximal thickness of the area preformed and the crease recovery angle of the treated area [8].

The mechanical properties including breaking strength and elongation to break of treated samples are evaluated in warp and weft direction with the LLYOD LS5 tensile tester according to the standard ISO 2062 (2014). The samples are conditioned during 24 hours in the relaxed state (22°C, 60% HR) according to the norm ISO 13934-1. For the tear strength properties is determinate with a ballistic method according to ISO 13937-1 using apparel "Elmendorf 275A". For the 3D thickness is according to ISO 5084. 3D ranks for treated fabric is evaluated then by rating the appearance of specimen in comparison with appropriate reference standards made with the association of an industrial panel as described in Fig.1. Rank 3 is the desired effect: it is standard compliant.

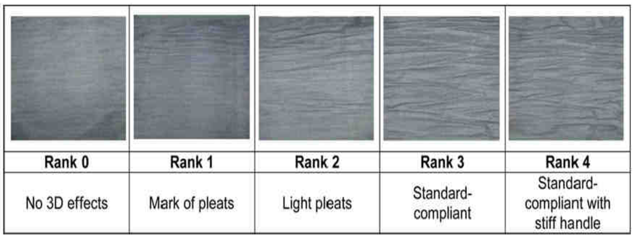

Fig. 1: 3D standards

The dry crease recovery DCRA properties were determined for treated fabric according to the standard norm ISO 2313 using a crease recovery tester model M003A SDL Atlas. The used load was 0.5 kg for 5 minutes, at temperature room. The samples for crease recovery measured (five measurements) were typically cut according to a special standard rectangular shape.

III. RESULTS AND DISCUSSION

3.1. *Analysis of main effect, interaction plot and contour plot*

1. Analysis of main effects plot

The main effect plot of various variables is presented in Fig. 2. It's clear that all response parameters Y1,Y2,Y3,Y4,Y5 Y6 and Y7 of DOE are influenced by the essentials factors (X1, X2, X3), while all response parameters are partial imperceptibly with the variation of factors (X4,X5, X6). Only, the response Y3 is depending of all factors variation. From Fig. 2, graphic showed that for the resin concentration X3, it affects in a significant way the

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tearing strength in the warp direction and also structure. In fact, the higher resin concentration increases causes damage in fabric structure and therefore the ability to tear strength increase, which is the case for showed responses breaking strength and elongation. The curing time is a factor related essentially to the resin concentration, but it affects turn internal links which explains its effect on different mechanical properties whatever tearing strength or breaking strength and breaking elongation. We also note that the amounts of catalyst PAZ, acetic acid and cationic additive 'Easystone super X' have no remarkable effect on the mechanical properties of the treated fabric, in except we can see the interaction between these parameters. For curing time has a contradictory effect in breaking strength. The curing time increase in warp direction, but decrease in weft direction, that probably be due to the interaction with resin concentration and to fabric characteristics. It's clear that, the catalyst PAZ (X4), acetic acid (X5) and Easystone super X concentrations (X6) have slightly effect on response parameters of DOE. Indeed, when the temperature increases internal links will be affected subsequently and the tear strength decreases, which is the case for the warp direction and the weft direction.

According to main effect plot (Fig. 2), it is noted that each factor acts on such an output parameter. Acetic acid is important because you cannot carry a resin treatment in an acidic medium. So we can never overlook it held fixed in the experimental after the value of 2 ($ml.l^{-1}$) of resin solution. The cationic additive acts on the textile substrate and with resin. It increases the affinity (cotton/resin) which is both negatively charged. So practically the amount of cationic X6 has no effect on the mechanical properties and that was proved by hand stud effect previously seen. Indeed, the resin is used in liquid form not crosslinked monomer suspended in solvent which prevents bridging between the pre-polymerized molecules. Under the action of heat or a catalyst (usually hardener) of covalence's strong bonds develop among all pre-polymer chains that finally become a crosslinked polymer of three dimensions. Thus the catalyst can improve the formation of macromolecular chains thus its amount is linked to the percentage of used resin. In reality, using a great resin amount X3 can increases the probability of crosslinking between the fiber and resin. Therefore the add-on rate is increasing between (5% - 20%) of resin concentration. Also it is clear that, using extra amount of cationic additive act on the add-on rate. Indeed, in experimental and under the same conditions with 0.3% cationic additive, the add-on rate increases from 4% to 10% compared to a value 0.06% of cationic additive. This occurrence it can be clarify with the nature product that can improve the affinity of the fabric to resin. The pH of the resin solution is always less than 4, 7 and it also does not exceed a 3, 95. In all cases, the medium remains acidic which is favorable for a resin treatment. This pH value is moderated by the addition of acetic acid. The quality of the 3D rank (Y7) is affected specifically by three major parameters: the curing temperature, curing time and the resin concentration.

2.1. Analysis of interaction plot

The graphic of interaction plot of mechanical properties and 3D ranks of treated fabric is presented in Fig. 3.

The interaction plot is a representation of the answers information averages for every factor level. The level of the second factor remained constant. This plot is useful to judge the presence of interaction. An interaction is present if the answer for a parameters level depends on/or the other parameters levels. In a diagram of the interaction, some parallel lines indicate the absence of interaction [7]. More the lines depart of the parallel; more the degree of interaction is raised. From Fig. 3 which present graphic of interaction plot of mechanical properties and 3D ranks of treated fabric, we obtain an interaction for all responses Yi with the factors X2, X4, X5 and X6. It determines that, the curing temperature, curing time, resin concentration and catalyst PAZ concentration: (X1, X2, X3, X4) are the most influencing factors for resin treatment. Also a strong interaction connects these four parameters. There is a strong interaction between the curing time and the resin Resacryl BD concentration which is relatively logical because if we increase the resin concentration, it requires more time to complete the polymerization. Also there is an interaction between the curing time and the catalyst concentration because it accelerates the reaction and then it reduces the polymerization time.

From previous results we can conclude that, the curing temperature, curing time and resin concentration are the primary factors which greatly affect the quality of fabric in terms of mechanical strength and especially the quality of 3D rank. Secondly there is the catalyst concentration PAZ.

The Fig. 2 showed that the loss in tearing strength in the warp direction Y5 is accentuated by increasing whatsoever the curing temperature or resin concentration; it varies between 20% and on about 27% in both cases. For the curing time is less intense effect, it is near 25%. The tear strength loss is as important in the weft direction Y6 but with a less percentage lower than in the warp direction. It varies between 16% and 19% for all parameters. This damage is acceptable because they have not exceeded the tolerance level that is 30% to 35%. Mechanical properties loss: breaking strength and elongation presented in Fig. 2 are acceptable because they have not exceeded 30%. All interaction plots showed (Fig. 3) that there is a close connection between the resin concentration and curing temperature and curing time already described above.

3. Analysis of contour plot

Contour plot of 3D rank parameter according others finishing factors presented in Fig. 4.

From Fig. 4, It's clear that to obtain best values of 3D rank more than 3 or 4 rank, it is favorable to select optimized values for others factors (X1 = 120°C, X2=30 min., X3 ≥ 150 $g.l^{-1}$) that presented a green dark area in contour plot. While, for factors (X5 and X6) haven't any effect directly or only in the 3D rank. This result has confirmed with main effect plot previously. In addition, the high value of X4 factor effect slightly the 3D rank because usually in interaction with factors (X1, X2 and X3). The amount of catalyst used in a reaction depends on the reactivity of the reactants and the time and temperature of curing. Any reactants having a low rate of reaction with cellulose require

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the use of a stronger catalyst and/or higher temperature and longer time for curing than do those reactants having a high reactivity [9].

III. 2. Mathematical Modelling

It used multiple linear regression method to model the relationships between the textile properties (3D rank), mechanical properties (breaking strength, breaking elongation and tear strength) and their process finishing parameters. The general regression equation (1) is used

Equation (1) $$Yi = a0 + \sum_{j=1}^{n} ajXj$$

Where;
Yi = (i = 1–7) are respectively: Breaking Strength warp, Breaking elongation warp , Breaking Strength weft, Breaking elongation weft, Tear strength warp, Tear strength weft , 3D ranks.
And X_j = ($_j$ = 1–6) are respectively: Curing temperature, Curing time, Resacryl BD resin concentration, Catalyst tem PAZ concentration, Acetic Acid AA concentration and 'Easystone super X' Cationic additive concentration. For a_0 and a_j are constants obtained by regression and is the number of variables. The regression equations obtained shown in Table 4.

A statistically significant interaction was found between the resin concentrations, curing temperature and curing time, i.e. the effect of curing time was found to be dependent on the resin concentration. At lower resin concentration, the effect of increasing time is considerably significant in reducing the fabric mechanical properties due to effective resin crosslinking. However, curing temperatures has a negative coefficient with breaking strength and tear strength but positive coefficient with breaking elongation; these results explain the variation of treated fabric extensibility following resin treatment as the heat effect. While, the resin concentration has a positive coefficient with tear strength and a negative coefficient with braking strength and elongation. The effect of resin treatment factors in tear strength in warp and weft direction respectively Y5 Y6, presented a mathematical equation of regression not practically linear because the correlation coefficient R-Sq is near 50%, except for the (p value <0,005) with (X1, X2, X3) as is clear in Tables (4 and 5). These results obtained of responses parameters Y1, Y2, Y3, Y4 and Y7 are in correlation with all factors and can be modelling with linear regression equation. However, these responses were to be statistically significant with specify curing temperature, curing time and resin concentration as they have (p value<0,005 and R-sq >90%).

III.3. Optimization of the finishing resin solution

The results already obtained allow us to optimize the initial recipe. The factors X4, X5, X6 are eliminating in this part because they haven't a physically powerful effect on mechanical properties. Indeed, the percentage of catalyst PAZ is considered fixed, because it has been found that's directly related with resin amount. He will take the maximum value to ensure better performance. So, we vary the factors X1, X2, X3 (curing temperature, curing time and resin Resacryl BD concentration) that are most influencing of the previous results. The factors fixed are as following (X4 = 20 g.l-1, X5 =2 g.l-1 and X6 =6 g.l-1). It obtained the result in Table 6.

Mathematical modelling of response DOE

Mathematical modelling plays an important position in developing, analyzing and predicting the relationship from experiments with certain level of confidence. In this means, it is important to develop the relationships between the key process variables of resin treatment and the performance of fabric characteristics. Using Minitab software to optimize the variable of resin treatment, we obtain the regression equation presents in Table 7.

Table 7. Regression Equation

Regression equation	P Value	R-sq (%)
Y1 = 367 - 0,146 X1 + 0,623 X2 + 0,258 X3	0,000	94
Y2 = 303 - 0,304 X1 - 0,458 X2 + 0,334 X3	0,000	92,6
Y3 = 30,9 - 0,021 X1 - 0,034 X2 - 0,0047 X3	0,000	76,5
Y4 = 19,5 - 0,026 X1 - 0,0312 X2 - 0,0034 X3	0,000	93,6
Y5 = 51,6 - 0,105 X1 - 0,0863 X2 - 0,0530 X3	0,000	95,8
Y6 = 36,4 - 0,046 X1 - 0,0715 X2 - 0,0189 X3	0,000	99,8
Y7 = 0,73 + 0,025 X1 - 0,025X2 + 0,007 X3	0,519	56,8
DCRA = - 29,4 + 1,31 X1 + 0,425 X2 - 0,005 X3	0,243	81,8
3D Th = - 6,88 + 0,074X1 - 0,006 X2 + 0,0206 X3	0,001	82,9

After reduces the initials numbers of DOE factors (eliminate X4, X5 and X6) and from Table 7, we showed that majority linear equation regression of responses resin treatment are more significant. The response Yi $_{(i1--6)}$ have a (R-sq > 90%) and (p value = 0,000<0,005). They have a positive constant and a negative coefficient with curing temperature and time. In addition, the DCRA and 3D thickness are considerably acceptable (quantitative response). While, for the response Y7 that present 3D rank has (p value > 0,005 and R-sq<<90%), so it's not significant, probably because they are (qualitative responses).

Objectively, in the aim of preserving the mechanical properties and will obtain the best 3D rank quality. From previously results, we have extracted two optimal recipes with pictures presented in Table 8 and Fig. (5-1, 2).

Table 8 Details of obtained optimal recipe and samples pictures with acrylic resin treatment.

Optimal recipe 1	Optimal recipe 2
▪ 13 % Resin 'Resacryl BD' concentration ▪ 0 ,2% Acetic Acid ▪ 2 % Catalyst PAZ concentration ▪ 0 ,6 % cationic super X ▪ Curing temperature 100°C ▪ Curing time 20 min.	▪ 9 % Resin 'Resacryl BD' concentration ▪ 0 ,2% Acetic Acid ▪ 2 % Catalyst PAZ concentration ▪ 0 ,6 % cationic super X ▪ Curing temperature 120°C ▪ Curing time 20 min.
	
Fig. 5-1) treated fabric with optimal recipe 1	**Fig. 5-2) treated fabric with optimal recipe 2**

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III. 4. Cationic additive quality impact on 3D rank of treated denim fabric

In order to compare five cationic additives type (cationic super X, Easystone K, Easystone MDR and Resicrome SG) and to select the best one, we choose the optimal recipe 1 of resin treatment.

Table 9 Details of fabric and recipe parameters with five cationic additives

Test	cationic additives	Add-on %	pH	3D Rank	DCRA	3D Th (mm)
1	Electroprep	61,88	5.17	4	108	4,3
2	Easystone K	61.68	4.49	3	101	2,1
3	Easystone MDR	62,04	4.45	4	97	3,8
4	Resicrome SG	63,07	4.31	3	92	2,3
5	cationic super X	60,06	4.52	4	100	3,6

From Table 9 showed that the add-on rate is important, it's more than 60% for different cationic additive. The pH values are almost the same for all resin solution, in except that the solution contains Electroprep it is 5,17. In fact, the pH of cationic additive affects the pH of resin solutions. (For Easystone K pH = 3.83, Easystone MDR pH = 3.9, the Resicrome SG pH = 3.8, the cationic additive super X pH = 4.2 and finally to Electroprep pH = 11), which explains the obtained results. Fig. 6 showed that the quality of 3D rank is excellent for Electroprep, the 3D rank is good for Easystone MDR and cationic super X. But Easystone K and Resicrome SG the 3D rank is weak. These results are also proven by the higher values of 3D thickness. DCRA of fabric after treatment is important is superior to the value 90 °. Mechanicals properties losses are important.

The breaking strength loss, breaking elongation loss, and tear strength loss were converted to codes (P1, P2 and P3) respectively. The strength loss property is reported as the force in Newton to break compared to the untreated fabric, in the warp or the weft direction. Table 10 present a strength loss values of mechanical properties (breaking strength, breaking elongation and tear strength) in warp and weft direction with five cationic additives.

Table 10 Mechanical properties loss with five used cationic additives

	Cationic additive	Loss values (N)		
		P1	P2	P3
Warp direction	Cationic super X	5,44	5,87	22,25
	Electroprep	4,48	0,19	19,96
	Easystone K	9,38	4,73	28,13
	Easystone MDR	8,98	5,42	22,85
	Resicrome SG	4,27	1,16	29,62
Weft direction	Cationic super X	1,48	6,26	15,48
	Electroprep	3,92	2,5	13,55
	Easystone K	4,69	4,73	21,2
	Easystone MDR	4,46	6,3	19,78
	Resicrome SG	6,93	5,62	17,14

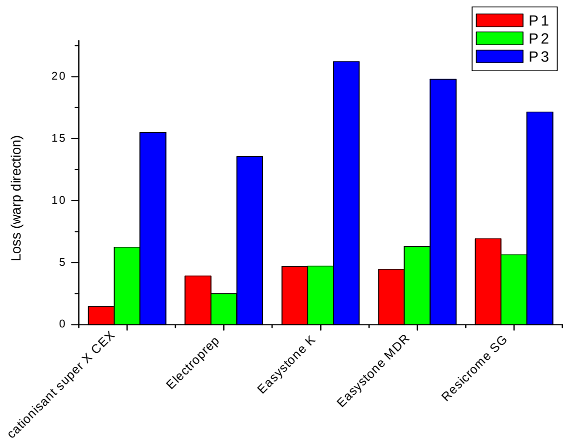

Fig.7: Strength loss of fabric (warp direction) with five cationic additives

Fig. (7, 8) showed that losses P3 of tearing strength are important in both directions: warp and weft and for all types of additives cationic, but they have not exceeded 30 %. The strength and elongation have less severe losses from the tear force. They are of the order of 5 % to 10 % in breaking strength and 1% to 6% in breaking elongation. We also clarify that Easystone K has the highest losses compared to other additives cationic.

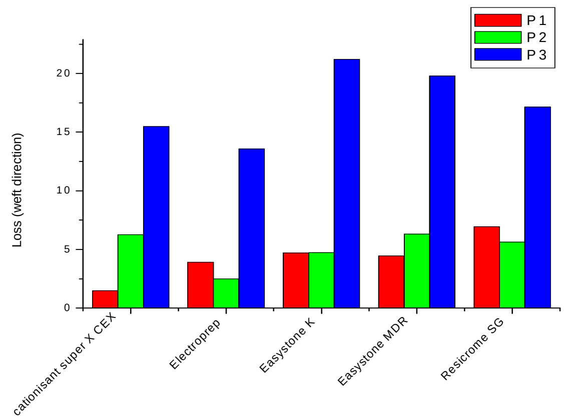

Fig. 8: Strength loss of fabric (weft direction) with five cationic additives

Comparing all additives cationic gives idea that Electroprep has the lowest losses and acceptable 3D rank, so it can change the great cationic super X by Electroprep. Indeed, for the results establish in this study prove that Electroprep gives us a good results and does not affect too the mechanical properties. In addition Electroprep has an environmental contribution in industrial textile.

IV. CONCLUSION

In this study, it have clarified that acrylic resin treatment depends directly too many finishing parameters. In essential, the curing temperature and time and resin concentration are the great influencing the resin treatment process. Additionally, the others additives products (catalyst, acetic acid) in resin recipe have an important together in

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crosslinking reaction, even as separately, they have a little effect on the mechanical properties (the breaking strength, breaking elongation, and tear strength) of cotton fabric. It has investigated the main effect of all design of experiments factors. Modelling all resin treatment parameters with DOE. Optimization of the resin recipe witch not damages the mechanicals properties of fabric is significant for desired quality finish. Finally, it have compared different additive cationic in resin treatment and we demonstrate that cationic type effect; in first level is (Electroprep). It has the best quality on 3D rank of treated fabric and affects a little loss on mechanical properties. In second level is (Easy stone super X), whereas (Easystone K) lead to a negatively loss on mechanical properties and gives undesired 3D rank.

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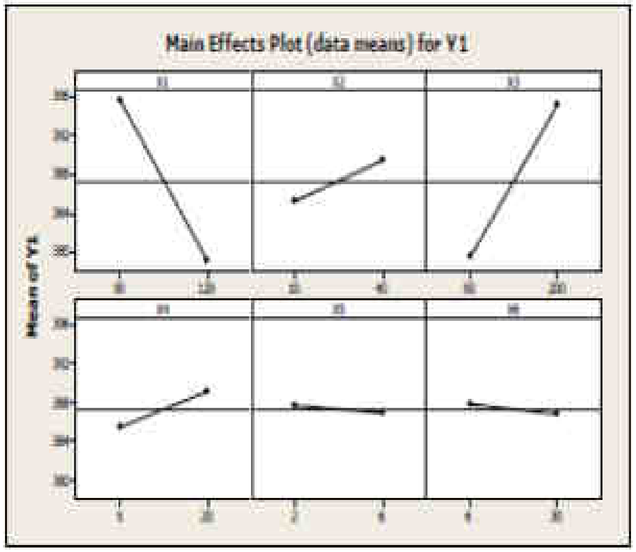
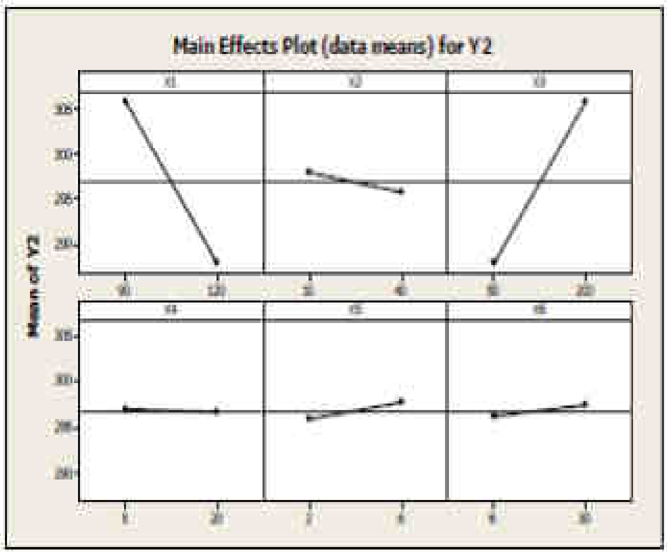
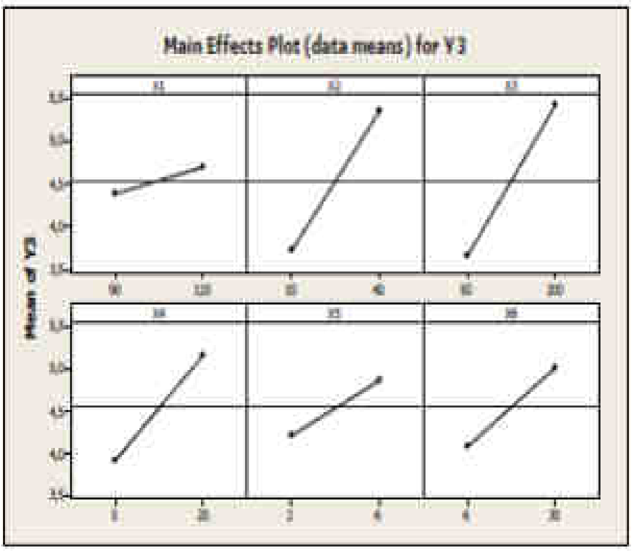
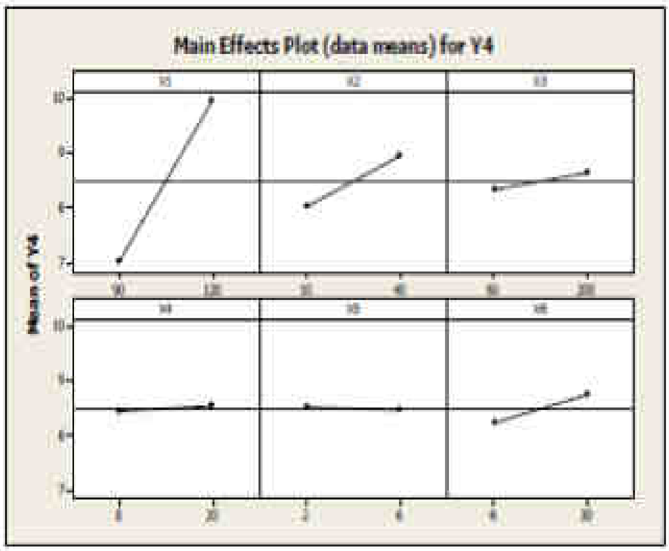








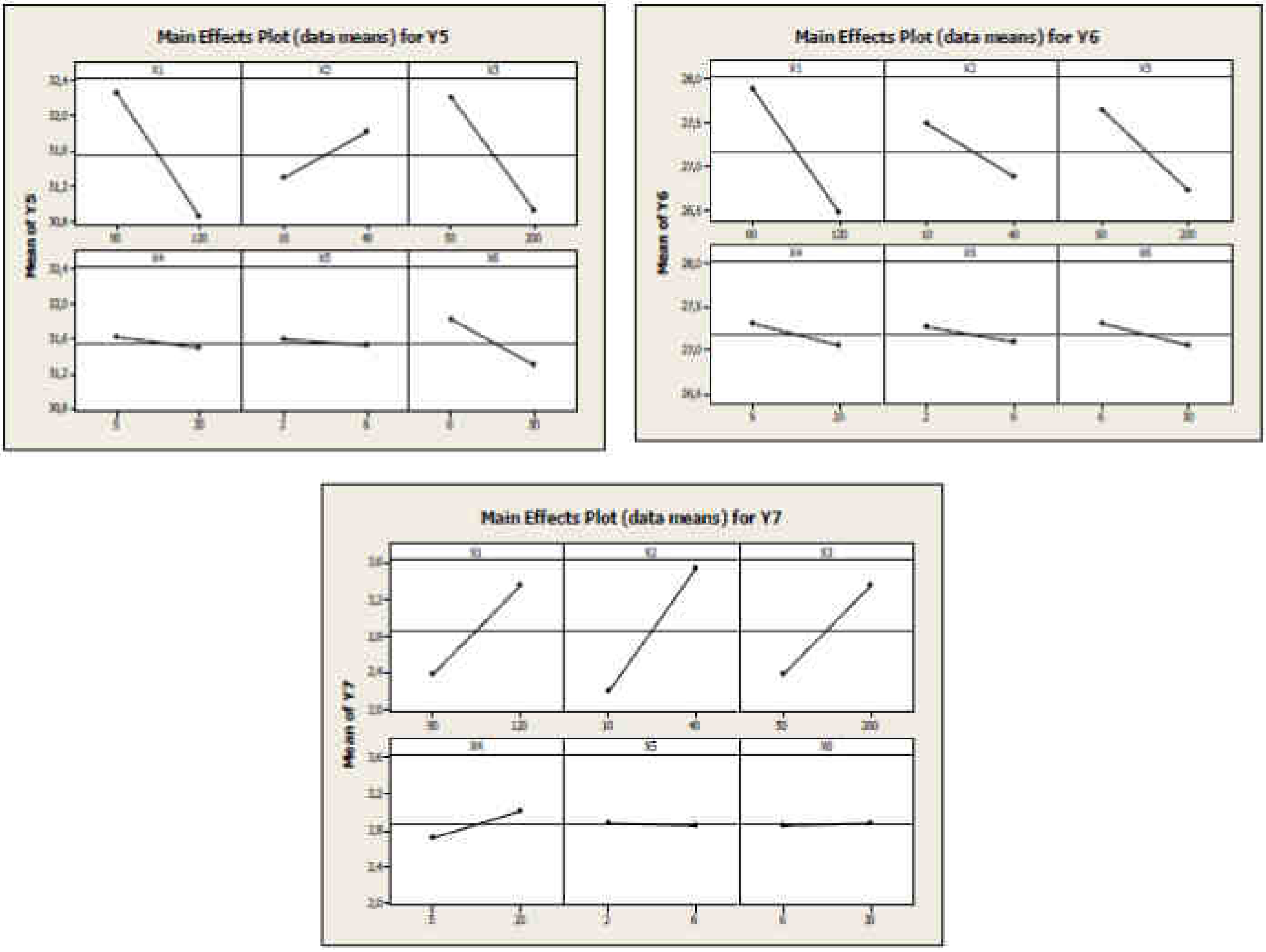
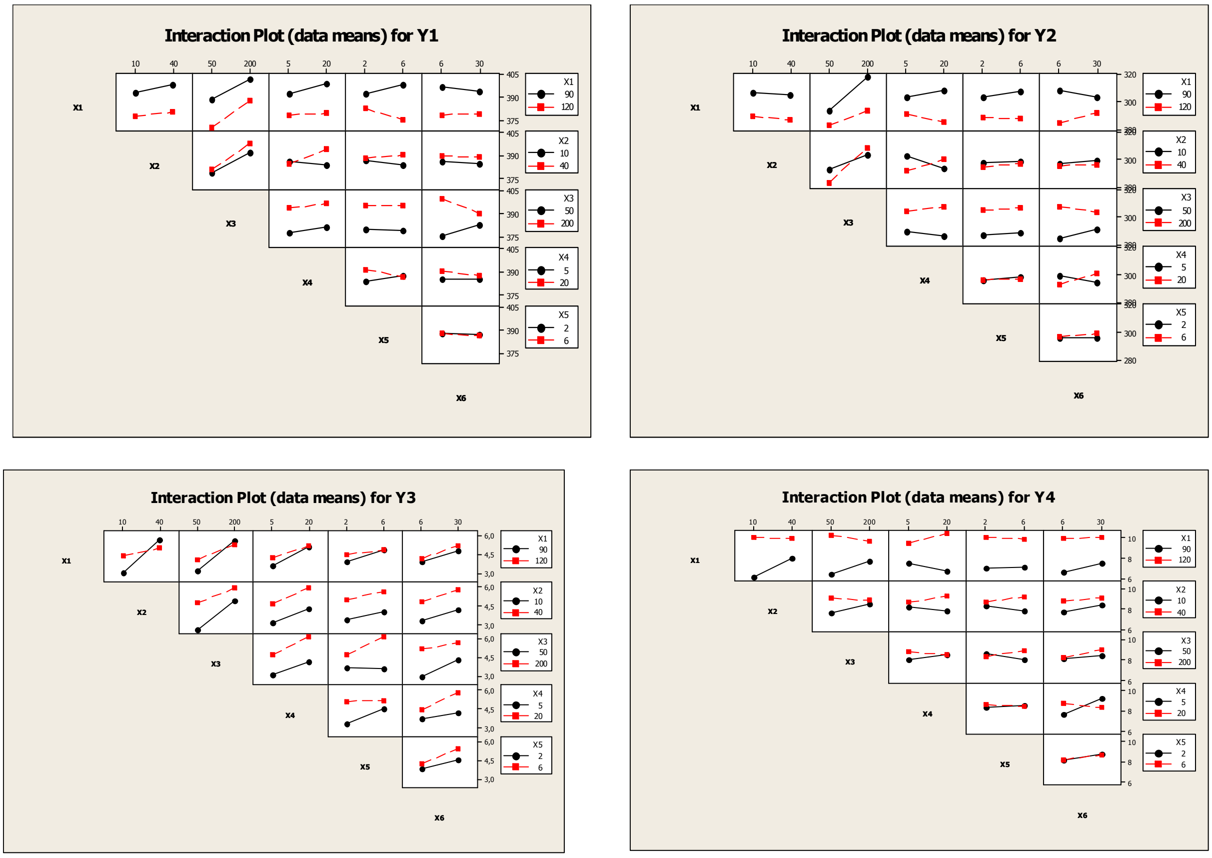


Fig. 2: Graphic of main effect plot of mechanical properties and 3D rank of treated fabric



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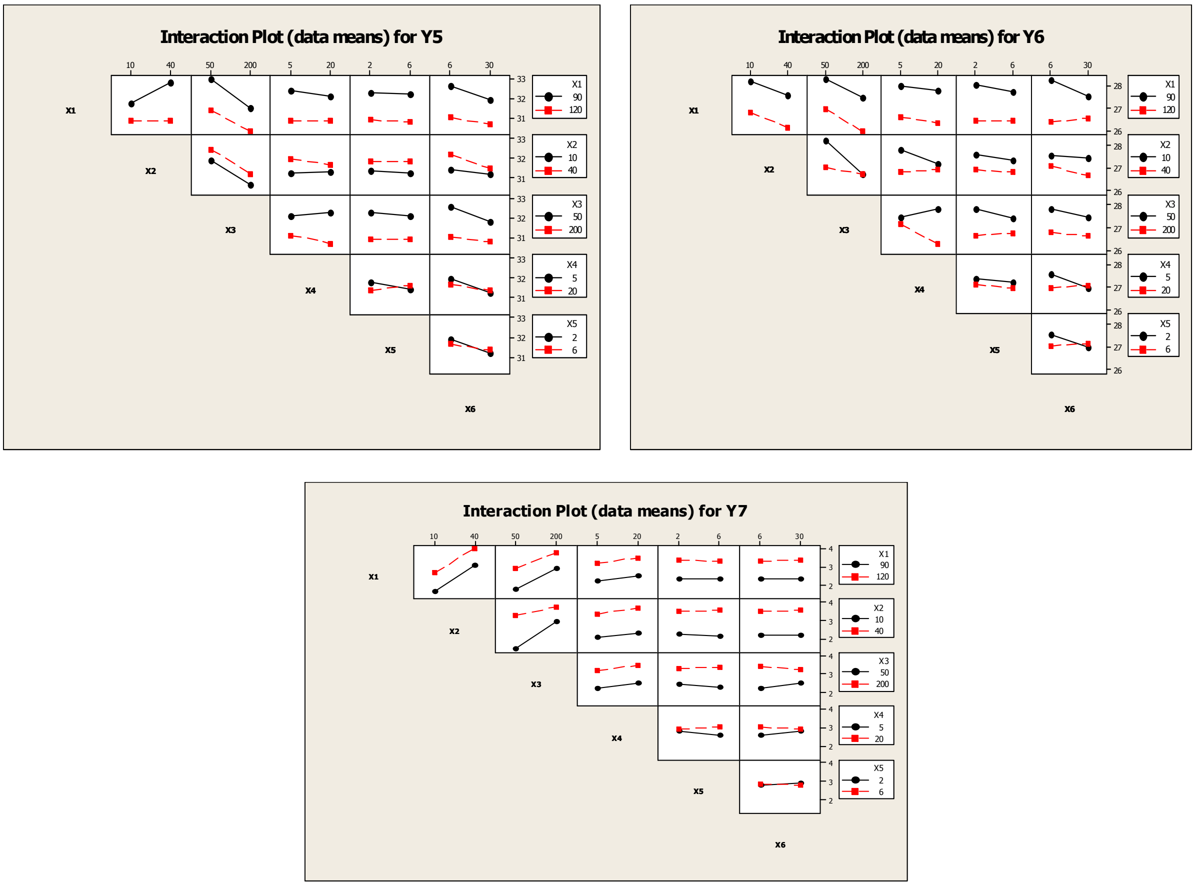

Fig.3: Graphic of interaction plot of mechanical properties and 3D ranks of treated fabric

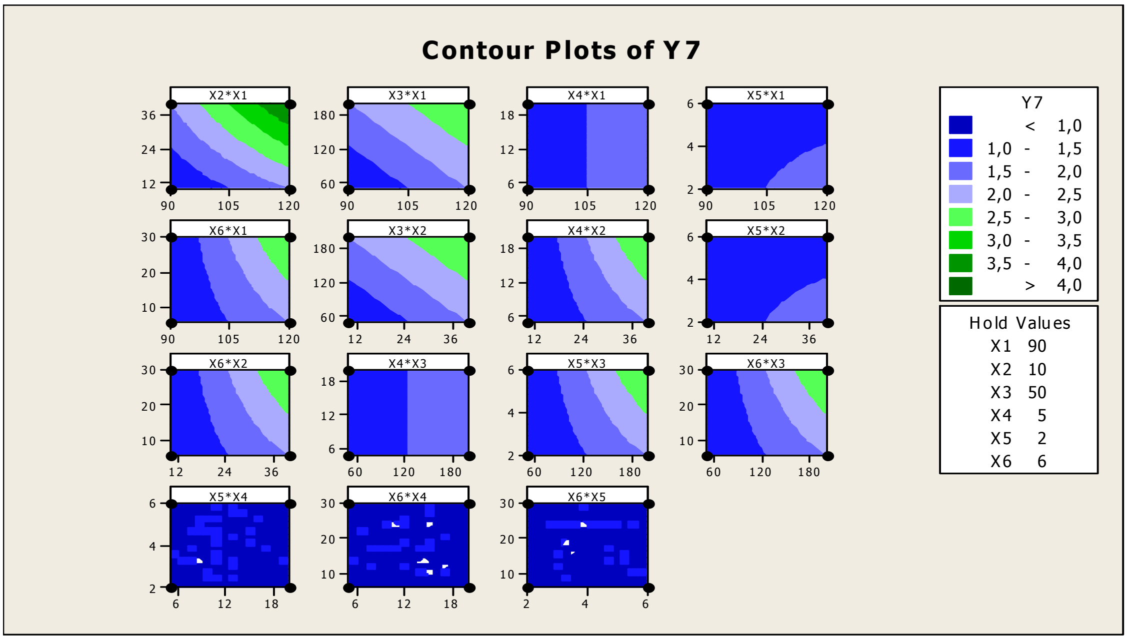

Fig.4: contour plot of 3D rank parameter according others finishing factors

Table 4: The Regression Equation

The mathematical equation of regression	R-sq
Y1 = 427 - 0,552 X1 + 0,138 X2 + 0,105 X3 + 0,245 X4 - 0,166 X5 - 0,047 X6	0,9
Y2 = 343 - 0,591 X1 - 0,075 X2 + 0,119 X3 - 0,023 X4 + 0,471 X5 + 0,053 X6	0,98
Y3 = - 1,75 + 0,0102 X1 + 0,0543 X2 + 0,0118 X3 + 0,0822 X4 + 0,163 X5 + 0,0387 X6	0,85
Y4 = - 3,34 + 0,0985 X1 + 0,0306 X2 + 0,00220 X3 + 0,0067 X4 - 0,008 X5 + 0,0221 X6	0,88
Y5 = 37,7 - 0,0470 X1 + 0,0177 X2 - 0,00854 X3 - 0,0079 X4 - 0,0176 X5 - 0,0212 X6	0,56
Y6 = 34,0 - 0,0472 X1 - 0,0209 X2 - 0,00613 X3 - 0,0165 X4 - 0,0413 X5 - 0,0104 X6	0,51
Y7 = - 4,39 + 0,0458 X1 + 0,0521 X2 + 0,00833 X3 + 0,0250 X4 - 0,0156 X5 + 0,0026 X6	0,78

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Table 5 Estimated coefficients and p-values of significant model terms for different response variables

p Value	Y1	Y2	Y3	Y4	Y5	Y6	Y7
Constant	0,000	0,000	0,534	0,125	0,000	0,000	0,000
X1	0,000	0,000	0,662	0,000	0,000	0,000	0,000
X2	0,191	0,523	0,023	0,091	0,055	0,019	0,000
X3	0,000	0,000	0,014	0,539	0	0,001	0,000
X4	0,245	0,923	0,082	0,851	0,665	0,344	0,034
X5	0,833	0,595	0,353	0,952	0,796	0,529	0,718
X6	0,718	0,719	0,188	0,325	0,065	0,343	0,718

Table 6: Experiments details of optimization factors and results

Test code	X1	X2	X3	Add-on %	DCRA	Y7	3D Th (mm)	Y1	Y2	Y3	Y4	Y5	Y6
1	100	20	90	57,7	123	3	2	389,1	292,4	28,15	15,85	34,46	28,57
2	100	20	110	60	120	4	2,1	392,2	297,5	27,54	15,83	33,36	28,18
3	100	20	130	61,4	108	4	3,9	395,9	309,5	27,35	15,7	32,34	27,87
4	100	20	150	61,9	105	4	4,3	406,4	311,8	27,25	15,68	31,4	27,32
5	100	30	90	54	104	3	2,2	394,1	289,3	27,13	15,68	34,15	27,95
6	100	30	110	55,9	113	3	2,6	402,5	294,1	27,08	15,59	32,97	27,4
7	100	30	130	57,9	112	3	2,9	404,1	307,2	27,05	15,58	31,56	27,08
8	100	30	150	59,4	110	4	3	408,8	309,9	27,03	15,55	30,77	26,69
9	120	20	90	55,8	128	4	4	384,3	289,2	27,02	15,49	33,05	27,55
10	120	20	110	58,8	131	4	4,1	390,9	292,9	27,02	15,47	31,09	27,24
11	120	20	130	59,6	133	4	4,3	393,7	303,5	27	15,31	30,62	26,93
12	120	20	150	65,7	135	4	4,5	404	308,9	26,92	15,28	29,75	26,53
13	120	30	90	57,6	140	4	4	392,3	286,6	26,84	15,04	31,95	26,93
14	120	30	110	59,9	145	4	4,2	397,9	286,9	26,81	14,97	29,91	26,45
15	120	30	130	66,2	146	4	4,9	401,4	293,4	26,79	14,95	29,05	26,14
16	120	30	150	70,6	147	4	4,9	405,5	301,7	26,77	14,75	28,81	25,83

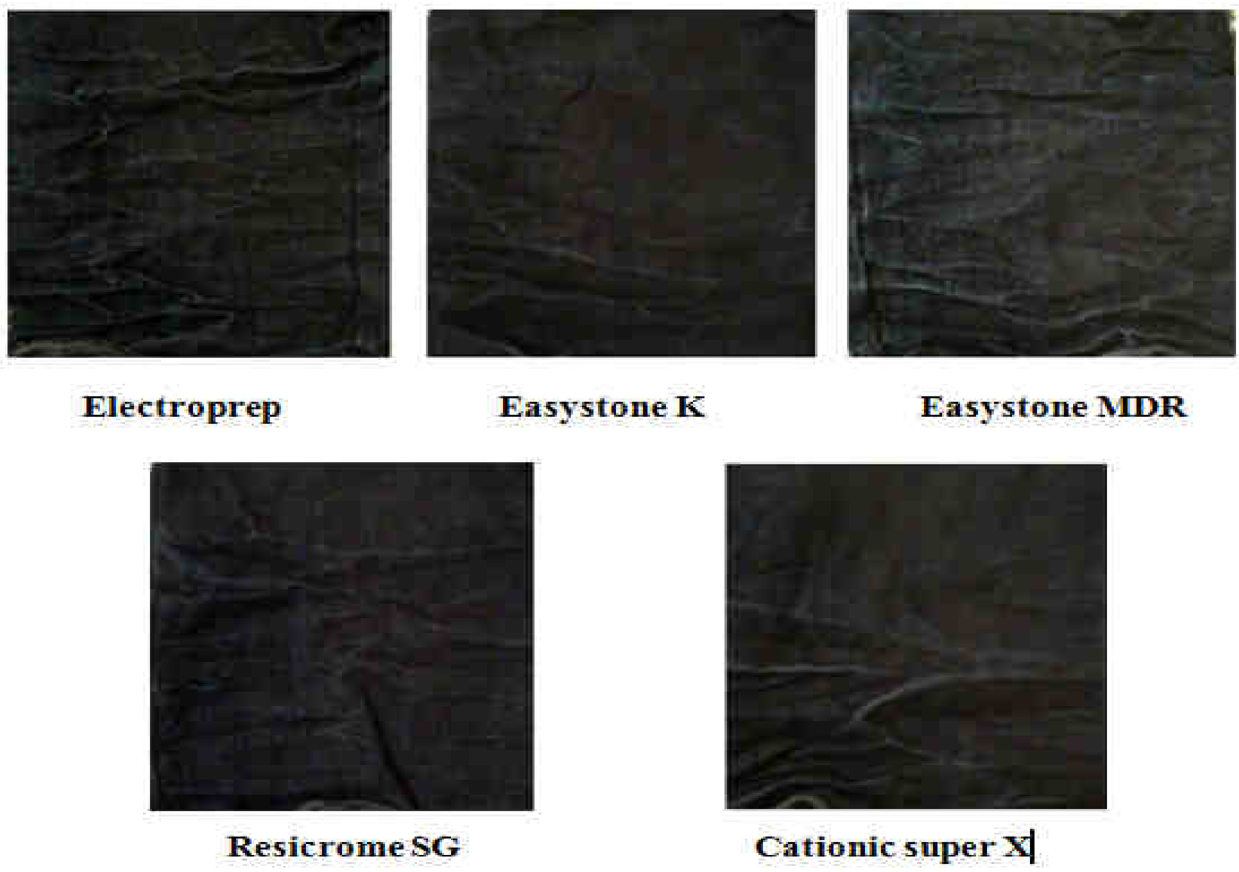

Fig.6: Pictures of 3D rank with different cationic additives on finished denim fabric

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