An Analysis of Sizing Process and the Properties of Sized Warps in Wet for WJL

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Abstract

Using orthogonal array method and analysis of variance, the sizing process for Water-jet Looms is fully investigated and the effects of four main factors and their interactions on the properties of sized filaments in wet are also analyzed. Among mechanical parameters, the abrasion-proof decreases very much, and the strength goes down slightly, but the elongation hardly changes in wet condition comparing with that in dry one. The type of sizing agents affects the properties of sized filaments most significantly. The properties of filaments sized by various sizing agents are quite different. Sizing agent No. 1 is the best one. The interactions between factors in sizing process also affected the properties of sized filaments. However, changing the single factor hardly causes the influence for the properties of sized filaments significantly. The optimum sizing conditions are suggested.

Key Words: Orthogonal array method, Analysis of variance, Sized filament, Mechanical parameter, Sizing agent

1. Introduction

Warp sizing is the most important process in the production of woven fabrics by Water-Jet Looms. It will directly affect the efficiency of weaving and the quantity and quality of fabrics. At present, it is usual way to use the single factor comparison for investigating the sizing process, that is, changing the single factor (for example, its concentration or its temperature, etc.), testing the efficiency of weaving, and then selecting the better technology of sizing. But it is difficult to find the best technology and to get the real conditions by using this method, the reason is that it overlooked the contact with each other among the factors, especially, the interactions between factors that affected the performances of sized filaments. In this paper, we make the experiments by means of the orthogonal array method with equal allocation, get the relationship among the factors of primary and secondary, which affected the performances of sized filaments using the direct analysis method of range and the analysis of variance [1-3], and obtain the best sizing process using the least test numbers.

2. Experimental

2.1 Experimental design

There are many factors affected the performances of sized filaments. Four main factors, the concentration of sizing liquor, its temperature, the pressure of the squeeze rolls and the sizing agents, are selected, and the two-factor interactions of former three factors are analyzed at the same time. Every factor has three levels. Samples are 8.33 tex/48f polyester filaments with circular cross-section. The sizing agents are obtained from the textile mills, used for water-jet weaving. Their main composition is shown on Table 1. The levels of every factor are listed in Table 2. Table 3 is designed to the experimental parameters using the table of orthogonal arrays.

2.2 Test conditions

The filaments are sized in the small sizing tester according to the table of orthogonal arrays of $L_{27}(3^{13})$ as shown in Table 3. The performances of sized filaments are tested in DCS-500 strength and elongation tester and the

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Table 1 Composition of Sizing Agents

No. 1	No.2	No.3
Ethyl acrylic acid	Ethyl acrylic acid	Ethyl acrylic acid
Methyl methacrylate	Methyl methacrylate	Methyl methacrylate
Butyl methacrylate	Butyl methacrylate	Butyl methacrylate
Saturated ethylene carboxylic acid	Styrene	Acrylonitrile
Acrylic	Methacrylate	Methacrylate

Table 2 Levels of Factors

Factors	Level 1	Level 2	Level 3
A Concentration (%)	9	8	7
B Temperature (°C)	50	45	40
C Pressure (kPa)	68.6	88.2	107.8
D Sizing agent	1	2	3

Table 3 Heading of Column Arrays for $L_{27}(3^{13})$

Column No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Factors	A	B	$(AB)_1$	$(AB)_2$	C	$(AC)_1$	$(AC)_2$	$(BC)_1$			$(BC)_2$		D

performance of abrasion-proof is tested in the Y730 abrasion tester. Their wet elongation and wet abrasion-proof performances are tested after the sized filaments are immersed in the water at 20°C for 20 minutes.

In the past, the dry performances of sized filaments were mainly analyzed, however, the wet ones were rarely investigated. Actually, although the time is short when warps are in wet in the water-jet weaving, their abrasion and elongation in the moisture condition will withstand the severe weaving condition than those in the moisture-free conditions. Their wet performances are worse than those in dry. Therefore, it is very important to analyze their wet performances in the water-jet weaving. The main parameters analyzed here are their wet strength, their wet elongation and their wet abrasion-proof.

3. Analysis of the results

3.1 Direct analysis of the result

Table 4 shows the results of test parameters. The influence grade of every factor for the tested parameters is analyzed using the method of direct analysis. The range R can judge the grade of influence. When R is large, it expresses that the grade of influence is also large, and usually the factor is primary one. On the other hand, the factor with little R is secondary one.

Table 5 indicates the primary-secondary factors affected the parameters according to their R. Some factors having larger R are temporarily regarded as the primary ones and some factors having less R as the secondary ones. For the wet strength, factors A, D and BC are the primary ones, where their R>4. Factors A, C, D, AB and AC are the primary ones affected the wet elongation, where their R>0.6. The others are the secondary ones. Factors B, D, AC and BC are the primary ones affected the wet abrasion-proof, where their R>9. The table shows that factor D is the most important one that affected the performances of sized filaments. That is, it is very important to select the sizing agents, because the significant differences of quality exist among three kinds of sizing agents. For factor D_1, its wet filament strength and its abrasion-proof are far larger than those by D_2 or by D_3, on the other hand, its sized filament elongation is slight larger than that by them. So, it is the best sizing agent among them. The wet abrasion-proof and the wet elongation by D_2 are higher than those by D_3, but its wet strength is lower than that by D_3. For factors A, B and C, the method of direct analysis can not judge the best level of every factor because their interactions for the performances of sized filaments are very large. Analysis of variance can further be used in judging and verifying their significance, their affected degrees for the parameters and their optimum levels.

Table 4 Results of Test Parameters

Experiment No.	Dry condition			Wet condition		
	Strength (N)	Elongation (%)	Abrasion-proof (t)	Strength (N)	Elongation (%)	Abrasion-proof (t)
1	4.035	21.896	160.5	3.895	21.766	108.6
2	3.876	20.936	129.6	3.930	20.574	65.4
3	3.916	19.082	132.7	3.877	18.536	64.8
4	3.876	20.200	127.8	3.857	21.192	54.6
5	4.003	20.948	192.6	3.892	21.892	111.8
6	3.952	20.470	132.6	3.879	20.246	55.5
7	3.945	21.572	129.6	3.900	22.140	67.9
8	3.872	19.616	183.4	3.901	20.457	57.5
9	3.931	20.336	161.9	3.793	19.428	90.3
10	3.851	20.017	168.5	3.845	20.902	56.0
11	4.053	21.438	170.9	3.945	21.332	110.6
12	3.968	18.923	143.9	3.902	20.653	65.0
13	3.964	20.556	142.6	3.849	20.674	62.8
14	3.822	19.316	165.2	3.904	20.226	69.7
15	4.006	20.806	178.9	3.967	20.230	94.3
16	4.121	22.577	177.1	4.015	21.568	106.3
17	3.914	21.126	134.5	3.893	20.846	61.3
18	3.870	19.774	196.7	3.905	20.004	50.9
19	3.928	18.496	145.9	3.834	19.002	71.3
20	3.893	19.453	180.8	3.897	21.838	65.7
21	3.970	20.468	193.9	3.879	20.450	118.7
22	4.023	22.532	179.9	3.901	21.024	80.9
23	3.866	18.360	147.0	3.775	19.982	63.3
24	3.927	19.740	175.0	3.825	20.726	68.7
25	3.926	21.162	177.6	3.846	20.762	55.0
26	3.973	20.958	147.9	3.806	20.168	76.1
27	3.874	20.990	131.3	3.841	19.218	66.9

Table 5. Direct Analysis of Parameters in Wet Condition

Parameter	Index	A	B	$(AB)_1$	$(AB)_2$	C	$(AC)_1$	$(AC)_2$	$(BC)_1$	$(BC)_2$	D
Strength	$\overline{T}_{(i)1}$	2.06	1.85	2.01	0.84	1.16	0.76	1.12	0.05	-0.67	3.98
	$\overline{T}_{(i)2}$	4.38	0.11	-0.32	2.41	1.19	1.55	2.71	2.02	4.13	-0.41
	$\overline{T}_{(i)3}$	-2.67	1.82	2.09	0.53	1.43	1.47	-0.05	1.71	0.32	0.21
	$R_{(i)}$	7.05	1.74	2.41	1.88	0.27	0.79	2.76	1.98	4.80	4.39
Elongation	$\overline{T}_{(i)1}$	0.69	0.15	0.56	0.29	1.00	0.48	0.93	0.48	0.32	0.87
	$\overline{T}_{(i)2}$	0.72	0.69	0.76	0.37	0.40	0.77	0.51	0.23	0.64	0.43
	$\overline{T}_{(i)3}$	0.00	0.57	0.09	0.74	0.00	0.16	-0.04	0.69	0.44	0.11
	$R_{(i)}$	0.72	0.54	0.67	0.45	1.00	0.61	0.97	0.46	0.32	0.76
Abrasion-proof	$\overline{T}_{(i)1}$	75.16	80.68	73.36	73.73	72.60	71.82	80.78	72.14	76.50	98.62
	$\overline{T}_{(i)2}$	75.21	72.40	72.39	77.34	75.71	79.34	71.34	70.90	76.60	64.38
	$\overline{T}_{(i)3}$	72.96	70.24	77.58	72.24	75.01	72.16	71.20	80.28	70.19	60.32
	$R_{(i)}$	2.25	10.44	5.19	5.10	3.11	7.52	9.58	9.38	6.41	38.30

Note: $\overline{T}_{(i)j}=T_{(i)j}/9$, j=1, 2, 3; $R_{(i)}=\overline{T}_{(i)j}\,\max-\overline{T}_{(i)j}\,\min$, i=1~13, j=1~3

$T_{(i)j}$ is the sum of data at level j; and

3.2 Analysis of Variance

Tables from 6 to 8 express the analysis of variance of each parameter for the orthogonal array tests. The significance of all factors is gathered together in Table 14. Table 6 shows factor D is highly significant when the wet strength of sized filaments is influenced by it. Combining with the table of direct analysis, we find that the strength of filaments sized by D_1 is the best; one by D_2 the second; and one by D_3 the last. Enhancing of their strength is depended on the strength of the filaments by causing the fibers to adhere together, the size film strength to make the outer surface of the filaments and its waterproof performance. Because the viscosity of sizing liquor D_3 is the largest [4], the sizing liquor is not driven into the filaments easily, its wet film strength is lower [5], and its waterproof performance is also the worst. Thus its strength of sized filaments is also lower. Factor BC influences its wet strength obviously. Two-unit table and Figure of interaction factor BC is separately shown in Table 9 and Figure 1. B_2C_3 is the best, and A_2 is the best when single factor A is inspected. It is not obvious that the wet strength

Table 6 Variance Analysis of Wet Strength

Source of variation	Sums of squares	Degree of freedom	Mean-square value	F	F critical value	Significance
A	232.35	2	116.18	11.76	$F_{0.01}(2,14)=6.51$	**
B▲	17.88	2				
C▲	0.41	2				
D	101.58	2	50.79	5.14	$F_{0.05}(2,14)=3.74$	*
AB	51.80	4	12.95	1.31	$F_{0.10}(4,14)=2.39$	
AC▲	38.16	4				
BC	136.27	4	34.07	3.45	$F_{0.05}(4,14)=3.11$	*
Error	81.81	6	9.88			
Sums	660.26	26				

Table 7 Variance Analysis of Wet Elongation

Source of variation	Sums of squares	Degree of freedom	Mean-square value	F	F critical value	Significance
A	2.979	2	1.490	5.705	$F_{0.05}(2,10)=4.10$	*
B	1.415	2	0.708	2.709	$F_{0.10}(2,10)=2.92$	
C	4.595	2	2.298	8.805	$F_{0.01}(2,10)=7.56$	**
D	2.663	2	1.332	5.100	$F_{0.05}(2,10)=4.10$	*
AB	3.180	4	0.795	3.046	$F_{0.10}(4,10)=2.61$	(*)
AC	5.976	4	1.494	5.726	$F_{0.05}(4,10)=3.48$	*
BC▲	1.387	4				
Error	1.227	6	0.261			
Sums	23.422	26				

Table 8 Variance Analysis of Wet Abrasion

Source of variation	Sums of squares	Degree of freedom	Mean-square value	F	F critical value	Significance
A▲	29.8	2				
B	546.1	2	273.1	5.25	$F_{0.05}(2,10)=4.10$	*
C▲	48.0	2				
D	7968.1	2	3984.1	76.62	$F_{0.01}(2,10)=7.56$	**
AB	187.2	4	46.8	0.94	$F_{0.10}(4,10)=2.61$	
AC	867.4	4	216.9	4.17	$F_{0.05}(4,10)=3.48$	*
BC	665.6	4	166.4	3.20	$F_{0.10}(4,10)=2.61$	(*)
Error	441.8	6	52.0			
Sums	10754.0	26				

Note: ▲ shows that the factor was merged into the error; and
** ,*, or (*) expresses the significance of each factor differently, when
$\alpha=0.01$, $\alpha=0.05$ or $\alpha=0.10$.

Table 9 Two-unit of BC of Wet Strength

	C_1	C_2	C_3
B_1	3.96	11.21	3.38
B_2	9.79	13.13	16.53
B_3	-3.32	-13.66	-7.02

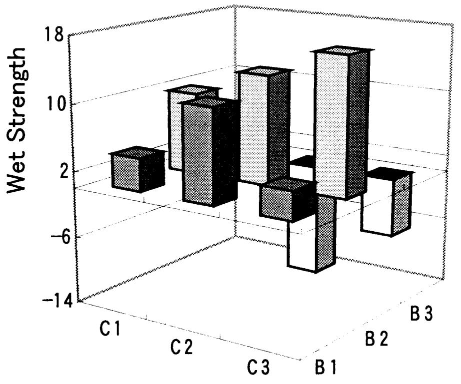

Fig. 1 Two-unit of BC of wet strength

Table 10 Two-unit of AC of Wet Elongation

	C_1	C_2	C_3
A_1	5.098	2.923	-1.760
A_2	3.144	2.404	0.887
A_3	0.788	1.988	0.394

Table 11 Two-unit of AB of Wet Elongation

	B_1	B_2	B_3
A_1	0.876	3.330	2.055
A_2	2.887	1.130	2.418
A_3	1.290	1.732	0.148

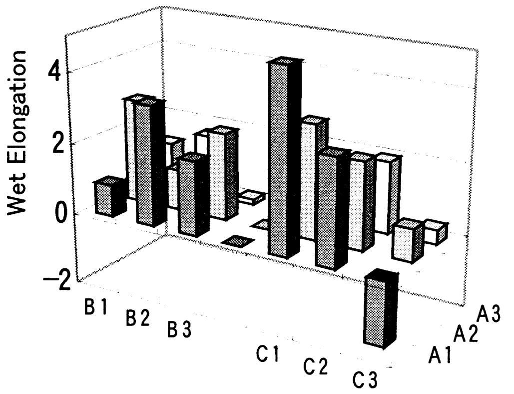

Fig.2 Two-unit of AB and AC of wet elongation

Table 12 Two-unit of AC of Wet Abrasion-proof

	C_1	C_2	C_3
A_1	231.1	234.7	210.6
A_2	225.1	241.6	210.2
A_3	207.2	205.1	254.3

Table 13 Two-unit of BC of Wet Abrasion-proof

	C_1	C_2	C_3
B_1	235.9	241.7	248.5
B_2	198.3	244.8	218.5
B_3	229.2	194.9	208.1

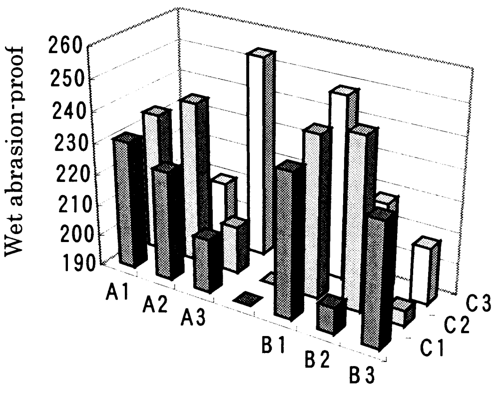

Fig.3 Two-unit of AC and BC of wet abrasion-proof

is influenced by factors B, C, AB, and AC. D_1 is best among Factor D_1, D_2 and D_3. Thus, $A_2B_2C_3D_1$ is the optimum sizing process only for the wet strength.

For the wet elongation, Table 7 indicates that the influence of factor C is highly significant, factors A, D and AC are also significant, and a factor AB is slight significant. Table 10, 11 and Figure 2 indicate the wet elongation is the largest when the factors and their levels are $A_1B_2C_1D_1$ combining with Table 5.

Factor D influences the wet abrasion-proof of sized filaments very obviously. The wet abrasion-proof of filaments sized by D_1 is much far higher than that sized by D_2 or D_3, and one sized by D_2 is slight better than that by D_3. The reason is that D_3 is a special sizing agent for polyesters, which shows high adhesive property with polyester filaments, and boosts the cohesion of fibers. The dry abrasion-proof of sized filaments is good, but its waterproof performance of the film is the worst. During weaving, the sized filaments are wetted and their films moisten and expand. The amount of dusting-off enhances during weaving. After parts of films dust off from the surface of filaments, the surface changes from smooth into rough, the coefficient of abrasion boosts, and the performance of wet abrasion-proof goes down, the number of end breakage increases during weaving. Agent D_2 is a general size one, and its adhesion with polyester filaments is not as good as that of agent D_3. However it has good waterproof performance, its wet abrasion-proof slightly reduces and is better than that of agent D_3 at wetting. For agent D_1, although it also is a general one, its recipe is more perfect. It has better adhesion with polyester filaments, and its film performance of waterproof is the best. Therefore, its sized filaments have not only good dry abrasion-proof, but also have good wet one. Factors B and AC influence the wet abrasion-proof very obviously. Other factors do not influence it obviously. We make Tables 12, 13 and Figure 3 of Factors AC and BC. The best level $A_3B_1C_3D_1$ is gotten combining with Table 5.

Generally speaking, the abrasion-proof decreases very much, and the strength goes down slightly, but the elongation hardly changes in wet condition comparing with in dry one. We consider the factors, the levels and the parameters in wet and dry conditions synthetically. On the basis of analyzing above and practical experience, abrasion-proof of sized filaments in wet is more important than others in weaving of WJL. We mainly inspect abrasion-proof of sized filaments in wet and take the others into consideration, and change multiple parameters into single one. Such, we can obtain the result, which is the optimum sizing condition $A_3B_2C_3D_1$.

Table 14 Significance and Optimum Level

Parameter	A	B	AB	C	AC	BC	D	Optimum Level
Wet Strength	**					*	*	$A_2B_2C_3D_1$
Wet Elongation	*		(*)	**	*		*	
Wet Abrasion-proof		*			*	(*)	**	$A_3B_1C_3D_1$

Note: ** ,*, or (*) expresses the significance of each factor differently, when α =0.01, α =0.05 or α =0.10

4. Conclusions

Our study investigated the relationship between the performances of sized filaments in wet condition and four main factors, which affect their properties. It is the type of sizing agent that affects the properties of sized filaments most significantly. The properties of filaments sized by the various sizing agent are quite different. Sizing agent No. 1 is the best one among them. The interactions between factors in sizing process also affect the properties of sized filaments. However, changing the single factor hardly causes the influence for the properties of sized filaments significantly. Hence, when we change the technology of sizing process, we must consider the interactions between factors.

The results indicate that it is the best to choose the low concentration (7%) and proper temperature (45°C) of sizing liquor. Using the sizing liquor with too high concentration can not improve the properties of sized filaments; on the contrary, it will worsen them. On the one hand, it causes the difficulty of driving the size into the filaments. On the other, it make the filaments contain too much size and the films of out-surface on the filaments are too thick. It will tend to be brittle, to reduce the strength, to worsen the abrasion-proof, and, as a results, an excessive number of end breaks will occur in weaving. The pressure of squeeze rolls will be placed slight largely, and it can increase the penetration.

In wet condition, the abrasion-proof descends very much, and the strength goes down slightly, but the elongation hardly changes.

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