CASE 27

Optimization of a Felt-Resist Paste Formula Used in Partial Felting

Abstract: In this research, by taking advantage of other easily obtainable paste agents in place of PNIPAM and minimizing the use of costly PVME, we attempted to apply the partial felting technique to jacquard cloth, which requires a variety of threads and fabrics. After optimization, a paste formula was developed successfully, resulting in a one-third cost reduction.

1. Introduction

Partial felting is a forming process based on felting shrinkage where by using a paste made primarily of heat-sensitive polymers as an antifelting agent, after printing a predetermined pattern onto wool cloth, it is felted above the temperature at which heat-sensitive polymers become insoluble. Through this process, the part not printed shrinks, whereas the part printed is not felted, and as a result, both felted and unfelted parts remain, creating an expressive appearance including rugged surface areas and various fluffs.

What felting means here is a phenomenon unique to wool (knitted) cloth, where because of cuticles on the surface of wool, its fibers are interwoven with each other, the wool shrinks in an irreversible manner, and subsequently, its texture becomes thicker and finer. This is similar to the case where a sweater made of wool shrinks after being washed and can never be returned to its original size. Unlike other common substances, heat-sensitive polymers are soluble in cold water but insoluble in hot water. PVME [poly(vinyl methyl ether)], especially, used in our study, is a very heat-sensitive polymer that quite acutely repeats the reversible states of becoming dissolved and clouded around 35°C.

Another heat-sensitive polymer, is a mixture of PNIPAM ([poly(*N*-isopropylacrylamide)] with PVME for partial felting. However, since PNIPAM has been obtainable only for experimental purposes and PVME is costly as a fiber-forming agent, it has been difficult for us to put this technique into practice. Therefore, in this research, by taking advantage of other easily obtainable paste agents in place of PNIPAM and minimizing the use of costly PVME, we attempted to apply the partial felting technique to jacquard cloth, which requires a variety of threads and fabrics. At the same time, we considered not only the anti-felting ability but also sufficient dyeablity.

2. Generic Function and Measurement Characteristics

We defined as ideal the state where, even if felted, the part printed by antifelting paste neither shrank nor warped: in other words, remained unchanged. Now we set the distance between each pair of vertices of the printed part to the input and the distance between the identical pair after felting to the output. The ideal is to have a zero-point proportional relationship with a slope of 1 between them.

As measurement characteristics, we used the before- and after-felted distances for 12 levels of each pair of vertices based on one unequilateral quadrilateral-shaped and two different triangle-shaped test pieces on which antifelting paste was printed. As a noise factor, considering that we apply the partial felting technique to jacquard cloth consisting of various types of threads and fabrics, we selected mousseline, which is made with a single-filament plain weave, and serge, which is made with two-up and two-down twill weaves, as test cloth. In addition, since actual products require different levels of felting shrinkage, we defined the felting time as a compound noise factor whose two levels are 50 and 70 min (Table 1).

On the other hand, this antifelting starch needs to have sufficient dyeability as well as antifelting capability because we wished to expand the number of products to which we can apply our partial felting technique. As for a measurement characteristic of dyeability, we use the *K*/*S* value that is derived from the theory proposed by Kubelka and Munk in 1913 and computed by the spectral reflectance of a dyed material. Ideally, the *K*/*S* value is proportional to the volume of dye included in test cloth. According to the orthogonal array, we mixed antifelting paste with dye with 1.0, 0.4, and 0.1% for each of the deep, intermediate, and light colors and printed each of them with the dies (Figure 1). The generic function of dyeability is expressed by a reference–point proportional equation having an origin where the line (showing the relationship between dye concentration in paste and *K*/*S* value) passes through the point of *K*/*S* value where the antifelt paste containing no dye is printed. Since the ability of antifelting and dyeability were different, we performed an analysis of each function separately and determined the optimal configuration by combining results.

3. SN Ratio and Sensitivity

Table 2 summarizes the data of experiment 1 in an L_{18} orthogonal array. Using them, we explain computation of the SN ratio and sensitivity. In this study we used dynamic characteristics of transformability.

Table 1
Noise factors

	N_1	N_2
Cloth type	Mousseline	Serge
Felting time (min)	50	70

Total variation:

$$S_T = 123.0^2 + \cdots + 83.4^2 = 493{,}403.9 \qquad (f = 24) \tag{1}$$

Effective divider:

$$r = 127.5^2 + \cdots + 90.5^2 = 276{,}021.8 \tag{2}$$

Linear equation:

$$\begin{aligned} L_1 &= (127.5)(123.0) + \cdots + (90.5)(88.0) \\ &= 269{,}879.3 \\ L_2 &= (127.5)(118.9) + \cdots + (90.5)(83.4) \\ &= 251{,}651.5 \end{aligned} \tag{3}$$

Variation of proportional terms:

$$S_\beta = \frac{(L_1 + L_2)^2}{2r} = 492{,}704.6 \qquad (f = 1) \tag{4}$$

Variation of differences of proportional terms:

$$S_{N\beta} = \frac{(L_1 - L_2)^2}{2r} = 601.86 \qquad (f = 1) \tag{5}$$

Error variation:

$$S_e = S_T - S_\beta - S_{N\beta} = 97.44 \qquad (f = 22) \tag{6}$$

Error variance:

$$V_e = \frac{S_e}{22} = 4.43 \tag{7}$$

Total error variance after pooling:

$$V_N = \frac{S_{N\beta} + S_e}{23} = 30.40 \tag{8}$$

SN ratio:

$$\eta = 10 \log \frac{(1/2r)(S_\beta - V_e)}{V_N} = -15.32 \text{ dB} \tag{9}$$

Sensitivity:

$$S = 10 \log \frac{1}{2r}(S_\beta - V_e) = -0.49 \text{ dB} \tag{10}$$

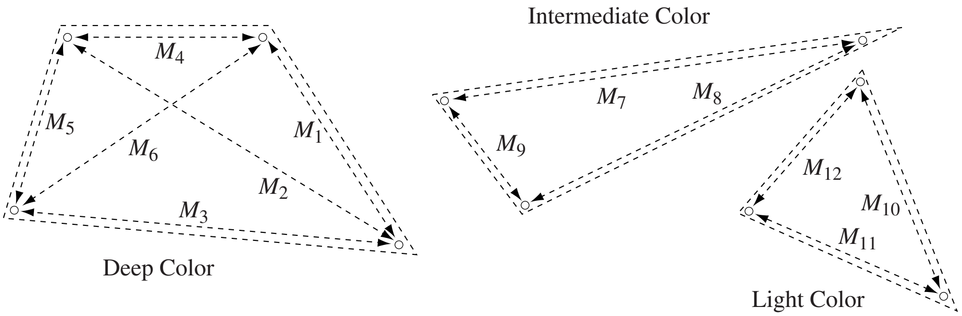

Figure 1
Signal factors

4. Optimal Configuration and Results of Confirmatory Experiment

As control factors, as shown in Table 3, we selected eight from the factors needed both for antifelting and for dyeability and assigned them to an L_{18} orthogonal array. Figure 2 illustrates the response graphs obtained from the SN ratio and sensitivity for each experiment based on the L_{18} orthogonal array. At the same time, as for dyeability, we calculated the SN ratios and sensitivities (but we omit them here). By focusing on the results regarding antifelting, we determined the optimal and worst configurations and confirmed them with confirmatory experiments. The results are summarized in Table 4.

These results prove that we obtained good reproducibility for both SN ratio and sensitivity. If we can recognize visually the difference between felted and unfelted portions in the partial felting process, we can evaluate quality using a six-point of inspection, then fine-tune to satisfy SN ratios and sensitivities. To this end, we adjusted the amount of heat-sensitive polymers used such that the total cost became minimal. For experiments 3, 6, 10, 14, and 16, all of whose visually inspected values are judged to be less than 2 (i.e., sufficient antifelting ability for partial felting), their average SN ratio and sensitivity are computed as −12.94 dB and −0.40 dB, respectively. The optimal configuration still allows these values to have a 0.66-dB slack for the SN ratio and a 0.04-dB slack for sensitivity. By reducing costly PVME with these slacks, we can slash the amount used from that at the optimal configuration by 20% in the SN ratios and by 27% in sensitivity. Computing the final cost of paste in accordance with the smaller reduction of 20%, we can arrive at approximately 850 yen/kg. As compared with approximately 2600 yen/kg when two types of heat-sensitive polymers are mixed in a conventional manner, this

Table 2
Experimental data (mm)

	M_1 (127.5)	M_2 (207.0)	M_3 (194.0)	M_4 (101.0)	M_5 (92.5)	M_6 (150.5)	Visual Judgment
N_1	123.0	201.0	188.0	99.0	90.0	146.6	5
N_2	118.9	187.4	173.0	89.6	86.0	136.0	5
	M_7 (230.5)	**M_8 (204.5)**	**M_9 (71.0)**	**M_{10} (126.5)**	**M_{11} (117.0)**	**M_{12} (90.5)**	**Visual Judgment**
N_1	228.0	202.5	69.0	123.5	113.5	88.0	3, 4
N_2	210.8	184.8	68.0	119.9	108.9	83.4	5, 5

Table 3
Control factors and levels

Control Factor	Level 1	Level 2	Level 3
A: mutual solubility improvement	LN: Type-1	YH: Type-2	—
B: print-dyeing paste	SM 4000	SH 4000	SH 4000
C: paste concentration	Low	Mid	High
D: PVME concentration	Low	Mid	High
E: osmotic agent concentration	0	Mid	High
F: uric acid concentration	0	Mid	High
G: pH adjustment agent	None	Malic acid	Ammonium sulfate
H: dry temperature	High	Low	(Low)

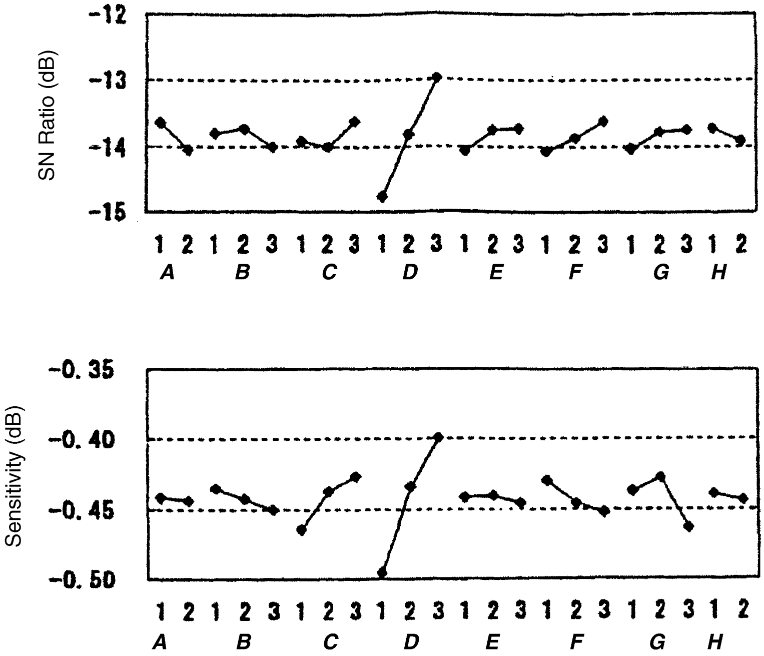

Figure 2
Response graphs

Table 4
Results of confirmatory experiment (dB)

Configuration	SN Ratio		Sensitivity	
	Estimation	Confirmation	Estimation	Confirmation
Optimal	−11.90	−12.28	−0.37	−0.36
Worst	−15.87	−16.20	−0.51	−0.51
Gain	3.97	3.92	0.14	0.15

cost reduction is one-third. Additionally, although the paste used currently often contaminates unprinted portions when mixed with dye during felting, the optimal paste does not cause the same problem, as long as the dyeing color ranges between light and intermediate, because we consider its dyeability as well. Considering this advantage, together with the cost benefit, we can obtain a greater economic benefit.

Reference

Katsuaki Ishii, 2001. Optimization of a felting resist paste formula used in the partial felting process. *Quality Engineering*, Vol. 9, No. 1, pp. 51–58.

This case study is contributed by Katsuaki Ishii.