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Compared Metaheuristic Methods to Optimize Industrial Ironing Process

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Abstract:
***Background**: This work deals with the optimization of industrial ironing conditions of weave cotton and wool fabrics. Indeed, input parameters related to the ironing process are investigated: sole plate temperature, steam flowtemperature and iron passages.*
***Materials and Methods**:Three metaheuristic techniques for optimization are applied to attempt the optimum ironing process within the suitable inputs: minimum surface thickness and minimum crease recovery.*
***Results and conclusion**: Based on the compared findings, genetic algorithms (GA) and particular swarm optimization (PSO)were found the adequate metaheuristic methods to optimize the fabric properties under industrial ironing. In fact, by comparing the GA and the PSO results and the experimental ones, the error values are considered low and reflect the effectiveness of the used technique for optimization. Regarding the findings obtained, there are sufficient correlations between theoretical and actual results and the coefficients of correlation are ranged from 0.818 to 0.914, which may reflect the accurate prediction and optimization of implementing metaheuristics methods in the specific design of interest.*
***Key Word**:Metaheuristic methods, optimization, wool and cotton fabrics, industrial ironing conditions, surface thickness, crease recovery angle.*

I. Introduction

Almost every type of product manufactured by the clothing industry is pressed/ironed both during and at the end of its assembly, or at the end only. The exceptions are items of underwear, which due to the materials and construction; do not require any form of pressing. Regardless of the extent of ironing, the function of the fabric composition and construction, it is a crucial process which imparts the final finish to a garment.

The key factor in cloth ironing is the heat. When temperature is beyond the glass transition temperature, Tg, of the polymer fibers forming the cloth; the molecules in the fibers of the wrinkled cloth acquire the energy to relax and return to their original, that is, unwrinkled positions, and then are fixed once cooled down. At a given time, other variables that also affect molecule relaxation will contribute to the result, notably pressure via the iron and high moisture from the accompanying steam, drying and cooling. [1, 2]

Many earlier studies [3, 4] have investigated the pressing conditions to optimize steam pressing. However, research was independent in terms of textile materials, pressing devices and characterization methods.

Smoothness appearance and touch are the firstly appreciated when selling cloths reflecting the quality of the final ironing. Many previous researchers judged subjectively ironed samples by comparing them to standard photographic given by standard test methods as AATCC 124 or AATCC 88C for examples.[5] Rawling et al. appreciated also easy iron properties of polyester, acrylic, wool, rayon, cotton fabrics using photographic technique.[6] Kishi et al. observed surface modification of fibers after ironing by electron microscopy.[7] The Sirolen press test was also used by Fan et al. and Jyothi et al. to measure pressing performance of fabrics. [8, 9] Chen et al. found that during steam ironing, different extensions are given to knit fabrics by using larger sized ironing boards. [10] A recent work of Shuaitong et al. investigated the pressure free vertical cloth ironing process on cotton fabrics. The importance of such process factors as temperature, steam amount, cooling wind and ironing time are examined to fit them into an empirical equation. [11]Shuaitong et al. studied the heat and mass transport phenomena in a system with steam jet flow to eliminate cloth wrinkles, a theoretical approach to derive the mean capillary radii was adopted so that a fabric can be characterized as an assembly of capillary tubes with varying diameters.[12] The crease recovery angle was found to be an effective method to evaluate press performance of light weight wool and wool blend fabrics after domestic hand iron. [13, 14, 15, 16]Jee have studied changes in dimensional and mechanical properties by KES-FB system of wool blended fused fabrics after pressing. Conflicting results on the dependence of fabric pressing performance on fabric mechanical properties have been reported.[17] The answer to this conflict may lie in the difference in pressing conditions and the specific behavior of the fibers.[18]

The optimization of the industrial hand ironing has not been approached in recent past except our previous works based on statistical techniques such as Taguchi design, response surface method (RSM) and desirability optimization method (DOM). [19]

The problem with this method lies in the difficulty of processing a high number of outputs and inputs, and the selection of input weights especially in multi criteria problems. Recovery angle, surface thickness measured using SIRO FAST system of cotton, polyester and wool fabrics were found to be the most influenced properties by industrial ironing conditions. Low stress mechanical properties were found slightly influenced by ironing process in the first cycles of ironing/laundering. [20]

The present study's aim is to apply metaheuristic techniques to optimize accurately the ironing efficiency, the crease recovery angle, and the surface thickness properties with some selected inputs during the ironing process. In fact, compared findings of crease recovery angle and surface thickness properties are discussed, in this paper, to select the best optimization method after the ironing process and to help industrials to select ironing conditions functions of fabric structure and composition.

The particular swarm optimization (PSO), ant colony optimization approach (ACO) and genetic algorithm method (GA) were used to select the input combinations giving the best industrial ironing conditions allowing best ironing efficiency.

1. Particular swarm optimization (PSO)

The PSO algorithm was inspired by the flocking behavior of birds and was originally proposed for single-objective continuous optimization problems. [21] It starts with a population of particles (often randomly generated), the positions of which represent potential solutions in the search space for the considered problem. Each particle has a fitness value which is given by evaluation of the objective function to be optimized and has its own velocity which determines the direction and speed of flying. In each iteration, each of the particles gets updated by making a tradeoff between following its current flying route (inertia) and heading for the two best positions that it knows (learning). The first one is the best solution it has achieved so far, and this is called the personal best position. Another "best" value obtained so far by any particle in the population, and this best value is a global best. The iterations continue with updated velocities and positions for each particle until the convergence criteria is satisfied, and then the best solution found so far is output as the final solution to the studied problem. [22, 23] The PSO method is widely used and successfully applied in many fields to resolve many multi criteria problems in textile research. [24, 25]

2. Ant colony optimization approach (ACO)

In the present work the ant colony optimization approach (ACO) was applied. The ACO approach was used to solve discrete optimization problems, in the late 1980s. [26] Indeed, it is based on the behavior of ants for finding food. They deposit pheromone as they walk and find their road by walking along the pheromone deposition. Density of pheromone deposition increases as ants walk back to source with food. Pheromone deposition on way back is dependent on both quality and quantity of food taken to the source point. Pheromone deposition/evaporation is directly related to number of ants traveling on that path. Ants find the optimal path by following maximum pheromone deposition (see Figure 1).

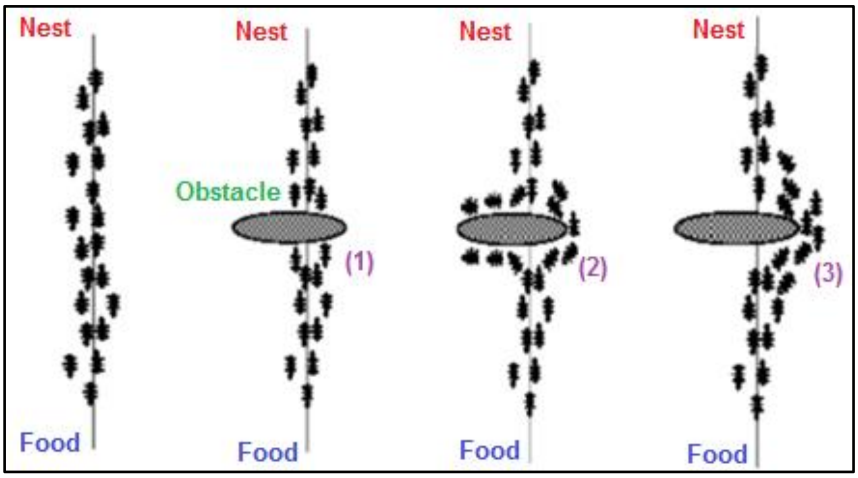

Figure no 1: The general behavior followed by ants during distance optimization

Artificial ants have now been successfully applied on a considerable number of applications leading to world class performances for problems like vehicle routing, quadratic assignment, scheduling, sequential ordering, routing in Internet-like networks and more. [26]

3. The Genetic Algorithms Approach (GA)

The genetic algorithm is an optimization technique inspired by the nature of living organisms, which is also referred to as the evolutionary algorithm. The genetic algorithm acts upon a population of potential solutions, and employs the principles of struggle for survival to produce better and better approximations to the solution to a problem. In every generation, a new set of approximations is built by the process of selection of the best member based on their fitness degree within the range of the problem and by reproduction via operators derived from natural genetics. This process, finally, ends up in population evolution of members having a better adaption to environment than the initial generation that is, in fact, their parents. [27] Many researchers suggested that genetic algorithm was the best tool to solve practical optimization problems, which are formulated and are mixed with continuous, discrete, and discontinuous variables. Generally, standard nonlinear programming techniques are not feasible for solving such problems. GA is a metaheuristic method, which used to optimize complex problems as used widely in the textile applications such as, fabric bagging behavior, fabric pattern generation, spinning production process, color fast finish process, fashion set design, etc. [29, 30, 31]

4. Linear Regression Method

The regression technique is used to fit and examine the relationship between the output or response parameter (y) and one or more input parameters called predictors (x). For a regression linear model (see Equation 9) with more than two predictors, the relationship between the modeling output y and the tested input parameters, x, can be presented as follow (see Equation 9): [32]

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ ... + \beta_k x_k + e \qquad (1)$$

Where:

y is the response or studied output,

x_i is the predictor or input parameter,

β_k represents the population regression coefficients,

e is the error term.

In the linear regression technique, the estimated coefficients indicate the change in the mean responses per unit increase in inputs when all other input parameters are held constant. If the p-value test (given by analysis of variance statistical test) of a coefficient is less than the chosen level, in our case it equals 0.05, there is evidence of a significant relationship between the input predictor or parameter level and the response. Besides, linear regression method results are discussed and are evaluated regarding the coefficient of determination of regression values. This regression coefficient (R^2) indicates how much variation in the response is explained by the model and how well the model fits experimental database. In fact, the higher theR^2, the better the model fits tested data.

The value of R^2 can be expressed in percentage. It is notable that, larger values (> 80%) of R^2 reflect models within widely prediction in the tested experimental design of interest. So, it is necessary to have a good relationship between tested data and the response, whereas the optimization has not any sense and signification. It is the first and the essential step before optimization using metaheuristic techniques.

II. Material And Methods

1. Materials

The investigation has been carried out with six popular woven cotton and wool fabrics differing with their mass area. The investigated fabrics used 60 cm × 60 cm (warp × weft) within their characteristics (see Table 1) are prepared for tests. The prepared samples are washed to eliminate the internal stress. Indeed, the fabric samples were all newly bought, the packaging, starching, etc., could make the fabric rigid and the internal force distribution non-uniform, which will influence the wrinkle making. Sets of specimens from selected fabrics were subjected to one laundering cycle, according to ISO 6330:2012.

Table no 1: Main characteristics of the tested woven fabric samples.

Composition		100% cotton			100% wool		
Fabric ID		#1	#2	#3	#1	#2	#3
Weave design		Plain	Twill 3/1	Twill 3/1	Plain	Plain	Twill 3/1
Yarn density, ends/cm	Warp	35.00	46.00	46.00	21.80	20.90	24.00
	Weft	32.00	24.00	18.00	21.00	18.00	24.50
Lineardensity, Tex	Warp	19.40	30.64	54.12	38.72	51.46	50.00
	Weft	20.20	30.84	59.32	30.40	50.86	50.00
Mass, g/m^2		138.00	228.00	344.00	146.50	204.00	262.00
Thickness, mm		0.32	0.56	0.80	0.33	0.60	0.72

As shown in figure 2, the schematic demonstrates how a typical steam iron works. The cloth sample is placed on heated working surface. The soleplate is heated to provide the sample with a prescribed ironing temperature. Steam nozzle attached tightly, but thermally insulated with the soleplate, supplies the steam during ironing. A centrifugal fan controlled by a pedal is needed to cool down the sample after the ironing process is completed. During each test run, the assembled steam nozzle and soleplate sweep the sample from the right to the left, spraying steam and heating the fabric. The set-up is such that the contact pressure between soleplate and the fabric is sufficiently small and uniform. Vacuuming time was fixed at 10 seconds and working surface temperature at 60°C. The vacuum sucks ambient air through the argument, as it lies on the buck or pressing table. This rapidly dries out residual moisture from the garment and ensures that the set imparted by pressing is retained.

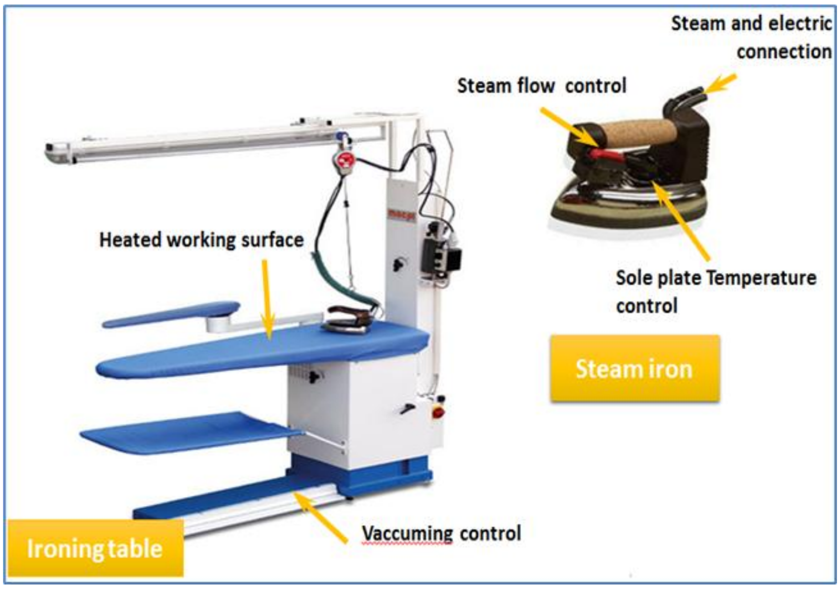

Figure no 2: Ironing apparatus

2. Experiment design

Four inputs, selected as influential parameters, were analyzed to evaluate their contributions on fabric properties after industrial ironing process.

We established a mixed-level factorial design of experiments (Taguchi design) to study simultaneously the effects of parameters (factors) on the measured properties (responses) and determine the best or optimal ironing conditions. In the current study, 18 different samples were tested.

Levels are chosen based on technical data of the device, but also on fabric composition (see table 2). In fact, ironing or pressing temperature depends to a large extent on the type of fiber and on the construction of the fabric or garment. In the case of blends, it is further suggested to use the temperature appropriate to the fiber with the lowest heat resistance. The indicated temperatures of the sole plate are selected from AATCC test method 133-2009. Heat from sole plate is needed to soften fibers, to stabilize and to set the desired shape. Steam is the fastest means of transferring heat into the fabrics. Pressure (or ironing passages) is applied to alter the wrinkled shape and to increase the permanency of the molding or creasing. Too much pressure may distort fabric surfaces, flatten textures and create shade and permanent fabric damage.

Table no 2: Factors and levels related to ironing process of selected fabrics

Coded input	Uncoded input parameters	Cotton fabrics			Wool fabrics		
		#1	#2	#3	#1	#2	#3
x (1)	Sole plate temperature, °C	150	175	200	150	165	-
x (2)	Steam temperature, °C	132	143	151	132	143	151
x (3)	Steam flow, g/min	33	83	-	33	58	83
x (4)	Iron passages	1	2	3	1	2	3

The input parameters ranged from x (1) to x (4) with their correspondent levels are obtained based on the industrial recommendations and manufacturer instructions of hand steam iron type MACPI 028 (2 kg on an industrial iron board (MACPI 160). The iron has a sole iron plate in aluminum and allows an exact temperature regulation with a tolerance of ±2°C. The steaming suction connected to the central steam.

Among all low strength mechanical and physical properties controlled after industrial ironing process, we have retained, previously, only surface thickness measured by the SIRO Fast System and crease recovery angle as properties highly affected by industrial ironing process. [33]

The tests were conducted according to the FAST instruction manual. Indeed, FAST is a simple fabric objective measurement system for assessing aspects of the appearance, handle and performance properties of fabrics. Moreover, FAST-1 is a compression meter enabling the measurement of fabric thickness and surface thickness at two predetermined loads. The fabric thickness is measured on a 10 cm² area at two different pressures, namely 2 gf/cm² (0.196 kPa) and 100 gf/cm² (9.81 kPa). This gives a measure of the thickness of the surface layer property (ST), which is defined as the difference between these two values. [34, 35]

The crease recovery angle in warp (θ-1) and in weft direction (θ-2) was measured according to ISO 2323. The ironed fabric specimen is creased and compressed under specified load and atmospheric conditions for a predetermined period (e.g. 5 min). After this, the load is removed, and the specimen is allowed to recover, once again under specified conditions and times (e.g., 5 min), and the recovery angle (crease recovery angle) is measured.

Different tests were performed in textile standard conditions (temperature = 20±2°C and related humidity= 65±2 per cent). All samples were preconditioned for 24 hours before starting measurements.

III. Resultsand Discussion

1. Statistical analysis findings

The regression technique is used to fit and examine the relationship between the selected properties of the ironed fabric and the influential input parameters of ironing. These properties are measured to evaluate and to optimize especially the input contributions. To determine the properties of the ironed fabric in the experimental design of interest, a fractional experimental design type Taguchi was elaborated thanks to MINITAB® 17.1.0 statistical software package. Hence, the regression technique is used to fit and examine the relationship(s) between the fabric properties called response parameters (ST, θ-1 and θ-2) of the ironed cotton and wool fabrics and the studied input parameters. Otherwise, it is the first step of optimization and should be completed to test and discuss the effectiveness of the relationships obtained between inputs and output presumed optimized in our specific design of interest. Notwithstanding, in case of low effectiveness and minimal efficiency of the regression results, the optimization analysis cannot be started because there is no significance between overall studied parameters. To improve the linear regression results based on coefficient regression (R^2) value as well as the analysis of variance results, statistical tests were discussed and analyzed. The behaviors of cotton and wool fabrics properties under ironing as a function of the studied inputs is traduced according to the multi-linear regression equations summarized in tables 3 and 4, respectively.

Table no 3: Multi-linear regression models of cotton fabrics

Fabric ID	Multi-linearregressionsmodels	R-sq, %	P -value
#1	ST = 0.38 - 5.3$10^{-5}$ x(1) - 2.89 10^{-3} x(2) - 8,91$10^{-4}$ x(3) - 3.84$10^{-2}$ x(4)	81.54	0.010
	θ -1 = 99.79 + 2.3$10^{-3}$x(1) - 2.44x(2) - 0.29x(3) - 1.8 x(4)	83.50	0.000
	θ -2 = 108.41 - 4.7$10^{-3}$x(1) - 2.57 x(2) - 0.28x(3) - 1.6 x(4)	84.17	0.000
#2	ST = 0.4 - 9.2$10^{-5}$x(1) - 1.07$10^{-3}$x(2) - 4.10^{-4}x(3) - 1.84 10^{-2}x(4)	82.90	0.010
	θ -1 = 133.58 - 2.23$10^{-2}$x(1) - 0.13 x(2) - 8.9$10^{-2}$ x(3) - 0.32 x(4)	83.37	0.000
	θ -2 = 110.32 - 2.2$10^{-2}$ x(1) - 0.15 x(2) - 5.5$10^{-2}$ x(3) - 0.34 x(4)	86.07	0.000
#3	ST = 0.315 - 10^{-5}x(1) - 7.7$10^{-4}$ x(2) - 2.7$10^{-4}$ x(3) - 3.2$10^{-3}$ x(4)	81.65	0.000
	θ -1 = 130.94 - 1.5$10^{-2}$x(1) - 0.10 x(2) - 8.9$10^{-2}$ x(3) - 1.85 x(4)	85.29	0.030
	θ -2 = 107.29 - 4.57 10^{-2}x(1) - 0.10x(2) - 8.6$10^{-2}$ x(3) - 0.59 x(4)	84.44	0.000

Table no 4: Multi linear regression models for wool fabrics

Fabric ID	Multi-linear regressions models	R-sq, %	P-value
#1	ST = 0.12- 6.4 10^{-3}x(1) - 3$10^{-5}$ x(2) + 10^{-6}x(3) - 2.75 10^{-3} x(4)	80.68	0.020
	θ -1 = 206.50 - 0.22x(1) - 0.14x(2) - 1.83$10^{-2}$x(3) - 1.64 x(4)	86.92	0.040
	θ -2 = 204.63 - 0.17x(1) - 0.16x(2) - 1.6$10^{-2}$x(3) - 0.47 x(4)	84.28	0.000
#2	ST = 0.14 + 5.6$10^{-6}$ x(1) - 3.2$10^{-5}$ x(2) - 2.2$10^{-4}$ x(3) - 1.33$10^{-2}$ x(4)	82.02	0.000
	θ -1 = 162.52 + 9.6$10^{-3}$x(1) - 3.85$10^{-2}$ x(2) - 4.1$10^{-2}$ x(3) - 0,69 x(4)	80.87	0.043
	θ -2 = 148.8 - 0.16 x(1) - 0.14 x(2) - 6.57 10^{-2}x(3) - 0.73x(4)	86.97	0.004
#3	ST = 0.33- 5.36 10^{-4}x(1) - 4.96$10^{-4}$ x(2) - 6.7$10^{-4}$ x(3) - 1.52$10^{-3}$ x(4)	80.52	0.000
	θ-1 = 254.2 - 0.39 x(1) - 0.29 x(2) - 2.17$10^{-2}$ x(3) + 0.12 x(4)	88.35	0.000
	θ-2 = 267.8 - 0.47 x(1) - 0.29x(2) - 2.40$10^{-2}$ x(3) - 0.6 x(4)	89.00	0.000

Apart from that the high significance values of the regression coefficient (close to 1) the selected fabric responses seem accurately predictable in the studied design of interest. The R^2value is ranged from 0.8068 to 0.9529 and can fruitfully explain that tested properties depend enough on the ironing input parameters. Thus, statistical models explain enough the good correlation between all the experimental values. However, to improve sufficiently findings obtained, a statistical analysis of variance test is applied using Minitab software. In addition, this statistical test helps to not only classify and evaluate both regression models within the investigated contributions of both the input and ironing process parameters, but also encourages the optimizations of their behaviors.

The statistical test was carried out to determine whether the regression model as well as the p-statistic value which was also saved and discussed. It helps to decide whether to reject or fail to reject a null hypothesis (the null hypothesis states that the effect is not significant). It appears that for the modeling, the multi-linear regression, as well as the significance of their input variables are mostly highly significant >80%. Their p-statistic values are under 0.05 which explain widely the importance of the established relationships between fabric properties and the investigated input parameters. [36]

Otherwise, using Taguchi design, the multi-linear regression and the analysis of variance statistical tests, it may be concluded that the findings founded seem fruitful.

Regarding these results, the behavior of selected fabrics can be successfully optimized and sufficiently predicted in our experimental field of interest.

2. Optimization using the metaheuristic techniques

Metaheuristic methods were applied and discussed to minimizing the surface thickness and crease recovery angle values. In fact, ironing decreases surface thickness giving flattened surfaces. The compressive force given by the sliding motion of the iron and the increase in temperature allows the yarn to undergo deformation nonlinearly, resulting in a change in thickness. [37] Surface thickness (ST) shows roughness of fabric surface and structural stability of a surface layer and the ironing imparted to a fabric must be stable to ensure the consistency of its handle and appearance. Basing on the ACO, GA and PSO technique steps, and referring to the behaviors (tables 3 and 4) the results of optimization are obtained and randomized.

a. Application of ACO approach

Using the ACO technique, the input parameters can be optimized accurately to obtain the best fabric appearance (minimal surface thickness and crease recovery angle). Several iterative tests were conducted to select an adequate value of the ants' number m that allows finding the optimal solution in a few times. It is notable that the number of ants presented high importance to random the result in the best solution. Figure 3 shows an example of surface thickness evolution after optimization as a function of the number of the ants used and the number of iterative cycles.

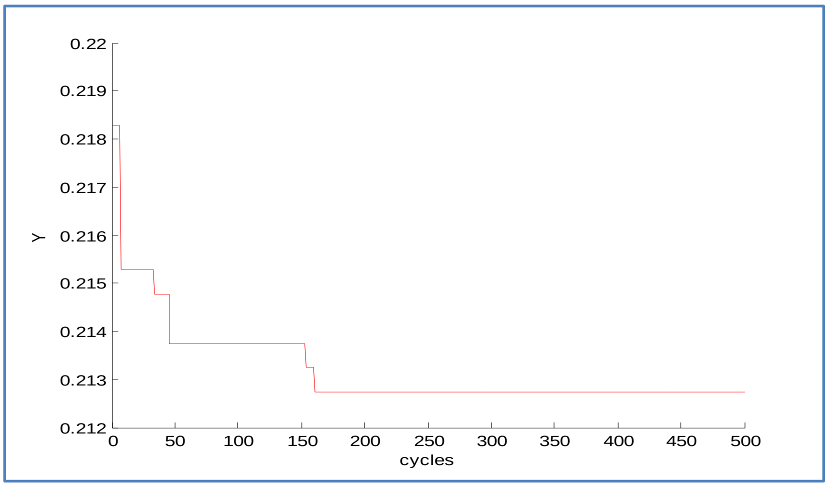

Figure no 3: Surface thickness evolution after optimization using ACO Method (cotton fabric #2)

According to our results 300 ants represent the suitable number giving the optimal surface and crease recovery angle in warp and in weft directions. In addition, using this technique of optimization, it may be concluded that after 162 cycles of randomization, the best value of surface thickness was occurred and equals 0.213 mm. Knowing that the program realized thanks to MATLAB software allows us to present the best inputs to ensure the minimal surface thickness value. So, at the end of the algorithm, the ants are able to take the best path. The results are satisfactory and reflect the accuracy of this method. The corresponding optimized input parameters to this optimal surface thickness, which equal to 0.213 mm, are 150°C sole plate value, 132°C steam temperature value, 33g/min steam flow and 1 iron passage. Table 5 shows all optimized results using the ACO approach for studied fabrics. In agreement with the results relative to figure 3, the same number of ants was saved.

Table no 5: The optimized output parameters using methaeuristic methods for studied fabrics.

Fabric ID	Output parameter	Cotton fabrics			Woolfabrics		
		GA	ACO	PSO	GA	ACO	PSO
#1	ST	0.097	0.299	0.174	0.105	0.107	0.105
	θ -1	58.571	80.156	57.898	143.318	134.305	143.033
	θ -2	64.977	89.041	66.306	148.980	136.269	148.980
#2	ST	0.131	0.212	0.128	0.122	0.126	0.122
	θ -1	99.779	126.850	99.779	149.412	156.131	152.436
	θ -2	76.630	84.405	76.635	93.690	116.188	93.696
#3	ST	0.150	0.190	0.150	0.157	0.181	0.157
	θ -1	98.869	110.172	98.867	142.165	154.717	142.165
	θ -2	99.032	83.250	73.071	142.967	138.454	142.967

However, tables 6 and 7 present all optimized inputs within their best surface thickness values and crease recovery angle characteristic ones obtained using the ACO method.

Table no 6: Optimal input parameters obtained using different methaeuristic methods for cotton fabrics

Optimization Method	Fabric ID	Output Parameter	Optimal input parameters			
			Sole plate temperature, °C	Steam temperature,°C	Steam flow, g/min	Iron passages
GA	#1	ST	150	151	83	3
		θ -1	150			
		θ -2	183			
	#2	ST	200			
		θ -1	200			
		θ -2	200			
	#3	ST	200			
		θ -1	200			
		θ -2	189			
ACO	#1	ST	150	151	33	1
		θ -1		132		
		θ -2		151		
	#2	ST		132		
		θ -1		132		
		θ -2		132		
	#3	ST		132		
		θ -1		132		
		θ -2		132		
PSO	#1	ST	200	151	83	3
		θ -1	200			
		θ -2	200			
	#2	ST	200			
		θ -1	150			
		θ -2	200			
	#3	ST	200			
		θ -1	150			
		θ -2	200			

Table no7: Optimal input parameters obtained using different metaheuristic methods for wool fabrics

Optimization Method	Fabric ID	Output Parameter	Optimal input parameters			
			Sole plate temperature, °C	Steam temperature, °C	Steam flow, g/min	Iron passages
GA	#1	ST	165	151	88.00	3
		θ -1	165		72.43	
		θ -2	165		88.00	
	#2	ST	150		88.00	
		θ -1	165		88.00	
		θ -2	165		88.00	
	#3	ST	165		88.00	
		θ -1	165		88.00	
		θ -2	165		88.00	
ACO	#1	ST	150	132	33.00	1
		θ -1				1
		θ -2				1
	#2	ST				1
		θ -1				2
		θ -2				2
	#3	ST				1
		θ -1				1

		θ -2				1
PSO	#1	ST	165	151	88.00	3
		θ -1	165			3
		θ -2	165			3
	#2	ST	150			3
		θ -1	150			3
		θ -2	165			3
	#3	ST	165			1
		θ -1	165			1
		θ -2	165			3

b. Application of GA approach

The GA technique was based on a combination between the different inputs as inspired from both natural generation and mutation, the best surface thickness and crease recovery angle values may not be obtained for the first iteration of the program. Figure 4 shows an example of surface thickness evolution after optimization using the GA approach as a function of the number iterative cycles (relative to cotton fabric #2).

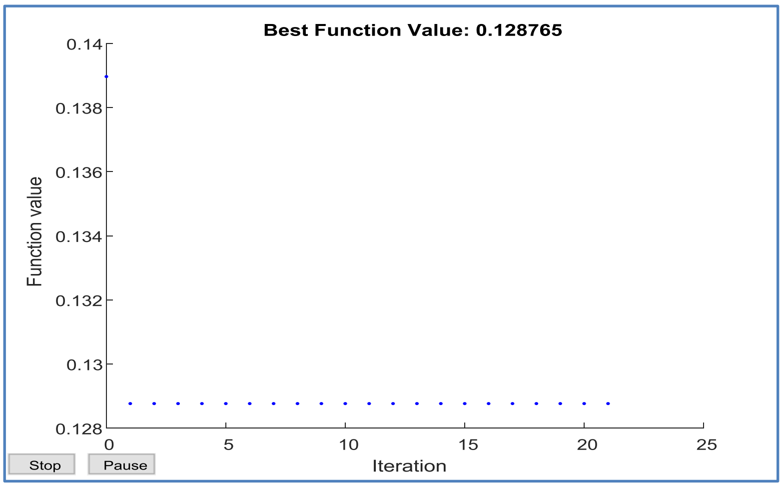

Figure no 4: Surface thickness evolution after optimization using GA method, (cotton fabric #2)

According to results, there are five generations which are recommended by the developed algorithm to optimize the surface thickness. Indeed, using the ACO approach, the lowest value corresponding to the optimal inputs is equal to 0.213 mm (see figure 3), whereas using GA, the value is 0.128 mm only. The corresponding optimized input parameters to this optimal surface thickness, which equals 0.128 mm are 200°C sole plate value, 151°C steam temperature value, 83g/min steam flow and 3 iron passages. Hence, these optimized input parameters obtained by this method are more severe than those obtained by the ACO method.

By comparing the different obtained values, the optimized input parameters as well as the best surface thickness and crease recovery were saved. Indeed, tables 5 and 6 show the optimized results within their suitable outputs using the GA method. Nevertheless, referring to tables 7 and 8, it may be concluded that most of the outputs were lower than those obtained by the ACO method. These methods do not present the same optimal fabric properties after ironing compared to ACO results.

c. Application of PSO approach

By comparing the metaheuristic and experimental findings, the minimal output values as well as the optimized input parameters were saved. Figure 5 shows an example of the optimized surface thickness evolution using the PSO method.

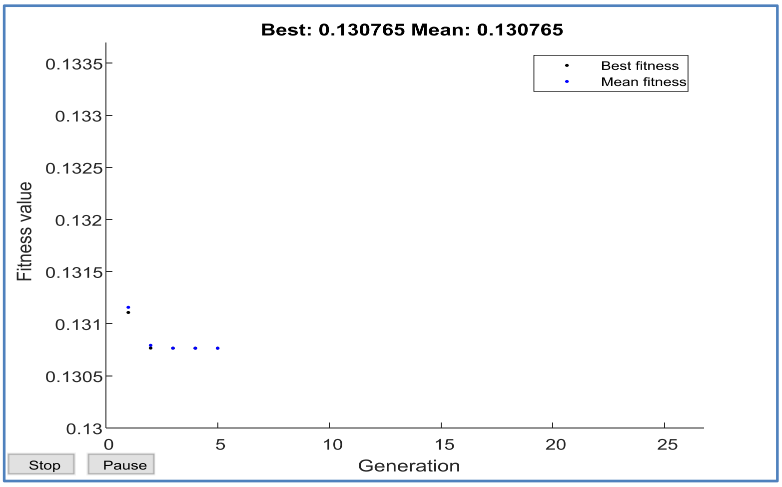

Figure no 5: Surface thickness evolution using PSO Method, (cotton fabric #2)

Furthermore, it is concluded from figure 5 that the lowest value corresponding to the minimum surface thickness value is equal to 0.130 mm, which is very close to that obtained by the GA method (see figure 4). Indeed, it may be concluded from tables 5 and 6 that the most optimized output parameters found using GA methods, was selected using the PSO method.

d. Optimal inputs parameters obtained using ACO, GA and PSO methods

In the case of cotton fabrics and for the same methaeuristic method, it can be noticed that only the sole plate temperature and steam temperature corresponding to the optimal surface thickness and crease recovery angle changed as a function of the fabric and the corresponding outputs. However, sole plate temperature, steam flow and iron passages have changed. Moreover, findings reported that no clear correlation can be retained between fabric construction (mass area/ thickness) and the energy required for ironing. This may be explained by the fact that we are operating at safe ironing conditions for wool and cotton fabrics, also by the slight difference in selected fabric mass area (light and medium weights). Nonetheless, no correlation is obtained in our previous works between fabric mass area/ thickness and ironing conditions. [33] In fact, during ironing and crease recovery test, the conditions of fabric deformation, as well as of recovery, are critically important and need to be carefully controlled and consistent. In addition, it seems the importance of the atmospheric conditions, relative humidity in particular, and the fiber moisture content during both creasing and recovery.

AG and PSO metaheuristic methods give best results and help the industrialists to determine their lowest fabric properties such as the surface thickness and crease recovery angle. Even so, to improve the optimized findings, the relative errors between experimental and theoretical properties (E_{PSO}, E_{ACO} and E_{GA}), are calculated as shown by Equations 2-4.

$$E_{PSO}(\%) = 100 \times \left|\frac{x_{PSO} - x_{Exp}}{x_{Exp}}\right| \quad (2)$$

$$E_{ACO}(\%) = 100 \times \left|\frac{x_{ACO} - x_{Exp}}{x_{Exp}}\right| \quad (3)$$

$$E_{GA}(\%) = 100 \times \left|\frac{x_{GA} - x_{Exp}}{x_{Exp}}\right| \quad (4)$$

Where:

x_{exp}: represents an experimental property (surface thickness, ST or crease recovery angle value) obtained after ironing test.

x_{PSO}, x_{GA} and x_{ACO}: represent theoretical property optimized using the PSO, GA and ACO methods, respectively.

E_{GA}, E_{ACO} and E_{PSO} : The relative error values involved by applying the metaheuristic techniques: GA, ACO and PSO and expressed in percentage.

Table 8 recapitalizes the overall compared results relative to the experimental and theoretical input/output parameters within their error values.

Table no8: The compared experimental and theoretical inputs/outputs parameters within their error values

Composition	Fabric ID	Surface Thickness			Crease recovery angle °, warp direction			Crease recovery angle °, weft direction		
		E_{GA} (%)	E_{ACO} (%)	E_{PSO} (%)	E_{GA} (%)	E_{ACO} (%)	E_{PSO} (%)	E_{GA} (%)	E_{ACO} (%)	E_{PSO} (%)
Cotton	#1	5.50	9.20	5.95	9.80	12.80	12.28	7.18	10.31	11.92
	#2	4.48	8.29	4.85	0.42	14.07	0.42	0.43	0.12	0.43
	#3	5.00	8.02	5.00	1.14	3.80	1.14	13.90	0.42	3.05
Wool	#1	1.74	0.00	0.47	1.56	13.51	1.76	0.68	13.20	0.68
	#2	0.00	6.34	0.00	3.07	0.74	0.36	1.37	12.85	1.84
	#3	0.31	3.25	1.68	0.58	1.12	0.58	0.71	11.80	0.02

Regarding the obtained error's values, it is notable that they can be considered as low. Thus, they reflect the pertinence and the effectiveness of the theoretical results. Among the all-calculated error values, there are those which seem high compared to the others. It may be explained by the significance of the R^2 values of almost regression models equals 80%. This finding seems in good agreement with those reported in the literature survey. Indeed, compared with the published works dealing with the significance of the coefficient of regression and they have been considered as highly significant (the R^2 values ranged from 68% to 72%), [38, 39] those obtained in the present work seem more efficient and fruitful. Therefore, comparing the theoretical results with the experimental ones; the GA, the ACO approaches seem accurate optimization methods to minimize crease recovery angle and surface thickness. These findings reflect the effectiveness of these techniques to optimize the studied database compared with experimental findings and help the industrialists as well as the researchers to implement their productions for further applications.

IV. Conclusion

Three metaheuristic methods are applied to decrease the crease recovery angle and surface thickness of tested cotton and wool fabrics subjected to industrial ironing conditions. To conduct this optimization, the influential parameters related to industrial ironing process are investigated as sole plate temperature, steam flow and temperature and iron passages. In addition, their levels are selected in the experimental design of interest based on fabric composition, technical data of the devices and industrial practice. Indeed, a Taguchi statistical analysis is derived and conducted. The findings obtained reported that the overall obtained statistical models seem relevant and traduce widely the behaviors of ironed fabric. In fact, their coefficients of regression (close to 100%), have ranged from 80.52% to 95.29% which are acceptable for the reliability of prediction and optimization. As a consequence, basing on these findings, ironing conditions are optimized fruitfully. Based on statistical analysis of variance and regarding the optimized results given by applying the metaheuristic methods (GA, ACO and PSO approaches), the fabric surface thickness and crease recovery angle properties were successfully decreased. It is notable that these responses are significantly affected by ironing conditions, according to our previous published works and researchers' ones.

Therefore, the compared results using the AG and the PSO approaches were adequate by offering the mean lowest error value and the optimal outputs. However, the optimal inputs obtained by the ACO technique seem better than those obtained by PSO and AG ones. To improve results, the optimized inputs are experimentally tested. Notwithstanding, no clear correlation can be remarked between the ironing conditions and the fabric physical properties (mass area and thickness). Thus, this difficulty is related to the iron ability (ease of ironing) that changes from one fabric to another in our case of interest. Moreover, by comparing the experimental and the metaheuristic results, the error values can be considered low and sufficient to improve the effectiveness of these techniques of optimization the ironing efficiency and help industrialists to predict their suitable input values.

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