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Fuzzy Modelling and Parametric Analysis of the Ring Spinning Process

Ring İplikçiliği İşleminin Parametrik Analizi ve Bulanık Mantık Metodu ile Modellemesi

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Araştırma Makalesi / Research Article

**FUZZY MODELLING AND PARAMETRIC ANALYSIS
OF THE RING SPINNING PROCESS**

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ABSTRACT: Ring spinning is the major manufacturing system to convert cotton fibres to yarns. It has been observed that in a ring spinning process, the settings of different spinning parameters determine its production efficiency and quality of the final yarn. Therefore, determination of the optimal parametric mix in ring spinning for having the desired yarn characteristics has been the main target of many research studies. In this paper, a ring spinning process is first modelled using fuzzy logic system and various yarn characteristics are then envisaged based on that model while exhibiting a close match between the observed and predicted values. For this purpose, the experimental data of two past research studies are deployed here. Besides this, the related interaction graphs are also developed to show the relationships between different ring spinning process parameters and yarn quality characteristics. These graphs play important roles in identifying the optimal parametric combination of a ring spinning process so as to achieve the target response values.

Keywords: Ring spinning; Fuzzy model; Parameter; Yarn characteristic; Interaction

**RİNG İPLİKÇİLİĞİ İŞLEMİNİN PARAMETRİK ANALİZİ VE BULANIK MANTIK
METODU İLE MODELLEMESİ**

ÖZET: Ring iplikçiliği, pamuk iplikçiliğinde kullanılan başlıca üretim sistemidir. Bir ring iplik eğirme işleminde, farklı eğirme parametrelerinin üretim verimliliğini ve son ipliğin kalitesini belirlediği gözlenmektedir. Bu nedenle, ring iplikçiliğinde hedeflenen iplik özelliklerine sahip olunabilmesi için optimal üretim parametrelerin belirlenmesi birçok araştırma çalışmasının ana hedefi olmuştur. Bu çalışmada, ilk önce bulanık mantık sistemi kullanılarak bir ring eğirme işlemi modellenmiştir. Daha sonra öngörülen ve gözlenen değerler arasında yakın bir eşleşme sergilenen biçimde bu modele dayalı olarak çeşitli iplik özellikleri tahminlenmiştir. Bu amaçla, geçmişteki iki araştırma çalışmasının deneysel verileri değerlendirilmiştir. Bunun yanı sıra, farklı ring iplik eğirme işlemi parametreleri ile iplik kalitesi özellikleri arasındaki ilişkileri göstermek için ilgili etkileşim grafikleri de oluşturulmuştur. Bir ring eğirme işleminin optimum üretim parametre kombinasyonunun hedef yanıt değerlerine ulaşması için tanımlanmasında, bu grafikler önemli roller oynamaktadır.

Anahtar Kelimeler: Ring iplikçiliği, Bulanık model, Parametre, İplik karakteristiği, Etkileşim

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1. INTRODUCTION

Over the years, two classes of spinning process have mainly been developed by people, i.e. hand spinning and machine spinning. Although there are various spinning technologies available to convert the raw cotton fibres into useable final products in the form of yarns, ring spinning process outperforms the others with respect to the achieved yarn strength and flexibility in production. Increase in the ring spindle speed is always sought by the spinning industry personnel for higher production at the minimum possible cost. As the total yarn production cost is seriously affected by the ring spinning cost, an in-depth study of this process is worth deserving so as to determine its optimal parametric settings. Process control in ring spinning thus becomes a pivotal activity as it affects properties of the final yarns directly. In a ring spinning process, there are several input parameters, like spindle speed, yarn twist level, traveller mass, top roller pressure etc. which play predominant roles in controlling the quality characteristics of the final yarn, such as yarn imperfection, hairiness, specific strength, breaking elongation, irregularity, breakage rate etc. [1]. Yarn quality is a concept which mainly depends on the customer demands for fulfilling several properties simultaneously. Yarn evenness is related with the variation in yarn fineness which can influence many properties of the yarn and fabric made from it. The strength of ring-spun yarn is also recognized as an important quality parameter. On the other hand, yarn quality is a crucial factor which decisively influences the fabric quality. Thus, from the point of view of producing high quality yarn with the desired characteristics, it becomes essential to operate a ring spinning process while setting its different control parameters at their optimal levels. For this, the spinning industry personnel have to rely on their own expertise or consult the manufacturers' operating handbooks. But, those parametric settings are often found to be conservative and significantly differ from one expert to another. In this direction, a fuzzy logic-based predictive model is proposed in this paper to help those personnel in setting various input parameters of a ring spinning process at their optimal operating levels for achieving a set of target yarn characteristics.

2. LITERATURE REVIEW

Lisini et al. [2] developed a mathematical model of ring spinning process through a complex system of differential equations while constituting a 'free-boundary' problem. The proposed model was subsequently solved by defining suitable boundary conditions of the mechanical characteristics of the process and spinning machine. Jackowski et al. [3] investigated the influences of linear density of the feeding sliver and yarn on their specific strength, elongation and elasticity in a rotor spinning process having the parametric settings as rotational speed of the rotor = 100,000 rpm, rotational speed of the opening roller = 7,000 rpm, and yarn linear density = 18, 20, 25 and 30

tex. A comparative study between rotor- and ring-spun yarns proved that rotor-spun yarns would be more suitable for knitting purposes because of their higher elasticity. Ahmad et al. [4] studied the effects on yarn strength and irregularity while varying twist multiplier (TM) and spindle speed in a ring spinning process. It was observed that the best combination of yarn lea strength and evenness could be attained at lowest spindle speed and TM. Based on Box-Behnken experimental design plan, Ishtiaque et al. [5] optimized three ring frame parameters, i.e. spindle speed, top roller pressure and traveller mass so as to attain better yarn quality and production. It was observed that a parametric combination of spindle speed = 15000 rpm, top roller pressure = 2.5 kg/cm² and traveller mass = 50 ISO No. would provide the optimal results. Üreyen and Kadoğlu [6] applied linear regression method to predict the most important yarn quality characteristics from cotton fibre properties measured based on high volume instrument (HVI) system. It was revealed that yarn count, twist and roving properties would contribute significantly to the considered yarn properties. Üreyen and Kadoğlu [7] developed the related linear multiple regression models to predict yarn count, twist and roving properties while using the advanced fibre information system (AFIS) data. It was identified that the considered fibre properties had predominant effects of the yarn quality. High values of coefficient of multiple determination proved the appropriateness of the developed models. Souid et al. [8] applied desirability function approach to determine the quality of ring-spun and slub yarns in order to simultaneously optimize a set of responses while satisfying the customers' requirements. The possibility of the application of global optimization superimposed diagram response surface methodology were explored to identify the spinner feasibility conditions so as to meet varying customer requirements. Lewandowski et al. [9] analyzed the effects of various parameters of a spinning process on yarn quality and production efficiency using multiple regression models. It was revealed that percentage of noils and metric coefficient of twist was the most important spinning parameters. Based on the developed models, the concurrent effects of both the parameters on cotton yarn and compact yarn properties were also studied. Tyagi et al. [10] investigated the effects of different spinning conditions, like spinning draft, twist factor, yarn tex and spindle speed on the structural, mechanical and low stress responses of ring- and compact-spun yarns. It was observed that with suitable twist factor and spindle speeds, yarns having less hairiness, higher abrasion resistance, and adequate structural integrity and compressional energy could be spun. Tang et al. [11] studied the yarn dynamical behaviour and twist distribution in a modified ring spinning process, and obtained the numerical solutions of yarn path, yarn tension and twist distribution in a steady state condition based on motion and twist wave propagation equations. It was concluded that the yarn paths in twisting zone could take several typical modes at varying yarn tension, and they would be roughly planar curves. Yarn paths and twist distributions were also evaluated based on experiments.

Dhange [12] endeavoured to validate different theories of hair formation, and studied the influences of different process parameters, like traveller, roving hank and TM on the contribution of left hand and right hand fringes of the spinning triangle to formation of yarn hairiness and hair length distribution. Continuous photographs of the spinning triangle were captured to exhibit the formation of different types of yarn hairiness. Based on linear regression and Monte Carlo simulation techniques, Ochola et al. [13] determined the effects of various fibre properties, like micronaire, fibre maturity, trash area, fibre length, fibre strength and fibre yellowness on yarn imperfections (neps, thick and thin places). A sensitivity analysis for the developed statistical models identified all the considered properties having influential roles on yarn imperfections. Feng et al. [14] applied fractional factorial design and response surface methodology to systematically study the quantitative relationships between different spinning parameters and physical properties of fine modified yarns. With the identified optimal parametric settings, fine modified yarn and woven fabric were manufactured and their properties were subsequently compared with the conventional ones. Using a four-factor three-level Box-Behnken experimental design plan, Khan et al. [15] studied the interactive effects of dyed viscose percentage in mélange yarn, spindle speed of ring frame, yarn TM and stitch length of fabric on yarn unevenness, yarn imperfections, yarn strength, yarn elongation and fabric GSM. The corresponding linear regression models were also developed showing the relationships between the considered input and output variables. Hasanuzzaman et al. [16] investigated the effects of three spinning process parameters, i.e. spindle speed, roving TM and yarn TM on six quality characteristics of ring-spun yarns, i.e. breakage rate per 100 spindles per hour, specific strength, irregularity, breaking extension, hairiness index and imperfections per km. Based on three-variable Box-Behnken experimental design plan, it was concluded that a combination of spindle speed = 17,000 rpm, roving TM = 1.3 TM and yarn TM = 4.1 TM could provide optimal values of all the considered yarn characteristics. Alakent and Issever [17] identified end breakage rate as an important quality characteristic to determine the yield of a spinning process, and analyzed a huge set of historical data using exploratory and predictive statistical techniques. Principal component analysis, correspondence analysis and artificial neural network models were suggested for use in textile industries for online monitoring, detecting faulty machines, choosing optimal machines for specific operational conditions and determining the range of process variables. From the extensive review of the existing literature, it has been observed that the past researchers have already developed diverse mathematical models to correlate different ring spinning process parameters with yarn quality characteristics. In this paper, an attempt is made to model a ring spinning process using the principle of fuzzy logic while correlating its various input parameters with the important yarn quality characteristics. The derived optimal settings of the two considered ring spinning

processes are perceived to be in close agreement with those as recommended by the past researchers. The experimental observations are also noticed to be in high agreement with the predicted values derived using the fuzzy model. The related interaction graphs are simultaneously developed so as to investigate the influences of the considered ring spinning process parameters on yarn characteristics and determine the optimal settings of those parameters in order to achieve the most desired responses.

3. MATERIALS AND METHODS

The ring spinning process is supposed to involve many variables and modelling of this process thus becomes a complex task. The nature of the input parameters to this process and the achieved yarn characteristics are largely stochastic rather than deterministic. In order to model a complicated process having vague/ambiguous properties, fuzzy logic [18], which is a mathematical approach combining multi-valued logic, probability theory and artificial intelligence, can play a crucial role. The foundation of fuzzy modelling is fuzzy set theory and linguistic statements which are mathematically expressed corresponding to the analysis of a human expert. The fuzzy system takes its decisions on inputs and outputs in the form of linguistic variables. These variables are tested with IF-THEN rules while generating one or more responses depending on which rule is assertive. The response of each rule is weighed according to the degree of membership of its inputs and the centroid of the responses is determined to derive the appropriate output. The composition of a fuzzy logic unit, comprising a fuzzifier, membership functions, a fuzzy rule base, an inference engine and a defuzzifier, is schematically exhibited in Figure 1. In fuzzy logic, the ranges of the considered variables are first identified which are often known as universe of discourse. Fuzzy rules in the form of linguistic statements depict the relationship between the inputs and outputs. The input and output variables are fuzzified and represented in the form of suitable membership functions (MF). The MFs are the construction blocks of fuzzy set theory, as it determines the fuzziness in a fuzzy set. Accordingly, the shapes of MFs are also important for a particular problem since they directly affect the fuzzy inference system. The only condition an MF must satisfy is that it must vary between 0 and 1. There are different shapes of MFs, like triangular, trapezoidal, Gaussian etc. [19]. The type of an MF mainly depends on the applicable area. Triangular MF is often used because of its various advantages, like calculations with triangular MFs are easy as it requires less information, ease in modification of the related parameters based on the measured values of input and output of a system, possibility to obtain input and output mapping of a model within a hypersurface consisting of linear segments, ability to attain the condition of a partition of unity etc. Linguistic variables are the input or output variables of the system being expressed in words or sentences from a natural language, instead of numerical values. These linguistic terms are used to classify each MF varying within 0 to 1. Taking higher number of linguistic terms results in more precise inputs to the fuzzy system achieving more accurate results. However, in this paper, three linguistic terms satisfy the required divisions to be

made for the considered inputs to the system, whereas nine linguistic terms are considered to define the output MFs for more accurate results. A MF simply maps each input to a membership value between 0 and 1. Usually, these fuzzy rules are developed based on the experimental observations and human expertise. In fuzzy logic system, the membership functions are the inputs to the fuzzifier in order to fuzzify the related parameters of a ring spinning process as they contain some degree of uncertainty with respect to the considered attributes. A fuzzy rule base consisting of a set of IF-THEN control rules is developed to show the inference relationship between the input and output. The inference engine performs fuzzy reasoning on the fuzzy rules while employing the Mamdani model of max-min inference for generating a fuzzy value. Fuzzy inference system is the process of formulating the mapping from a given input to an output using the principle of fuzzy logic. This mapping thus provides a basis from which the decisions can be arrived at. The output values in fuzzy logic are only available in terms of fuzzy values which need to be defuzzified for better interpretation. The fuzzy outputs are then converted into crisp numeric values. Although there are several approaches available for defuzzification, centroid of area defuzzification method has been popularly employed in fuzzy logic due to its ability to provide more accurate solutions.

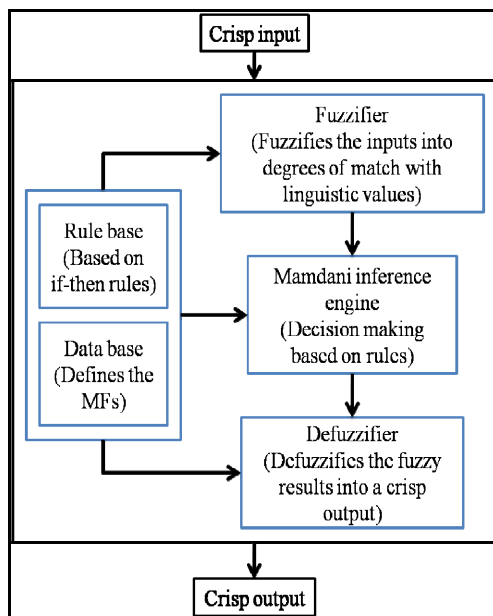


Figure 1 Fuzzy logic unit

4. RESULTS AND DISCUSSIONS

In this paper, the past experimental data of two ring spinning processes are considered so as to develop their corresponding fuzzy models and study the influences of various input parameters on yarn characteristics.

Example 1

Based on three-variable Box-Behnken factorial design plan, Hasanuzzaman et al. [16] conducted 15 experiments to study the effects of varying spindle speed (in rpm), yarn TM and roving TM on six important yarn quality characteristics, i.e. breakage rate per 100 spindle per hour (BR), specific strength (SS) (in g/tex), irregularity (IR), breaking extension (BE) (in %), hairiness index (HI) and imperfections per km (IM). The levels for the chosen ring spinning process parameters are shown in Table 1 along with their coded values. Those levels were so selected that they would all lie within the industrially acceptable ranges. The detailed experimental design plan and values of the observed yarn characteristics (responses) are provided in Table 2.

In order to model this ring spinning process using fuzzy logic system, ring spindle speed, yarn TM and roving TM are treated as the inputs, while the six yarn characteristics, i.e. BR, SS, IR, BE, HI and IM are the outputs. The architecture of the developed fuzzy logic model is exhibited in Figure 2. Fuzzy inference system is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which valuable decisions can be made or specific patterns can be identified. In this paper, the Mamdani model is considered for mapping the relations between the inputs and outputs. The inputs are represented by triangular MF having three different fuzzy subsets as low (L), medium (M) and high (H). On the other hand, another triangular MF is considered for the yarn characteristics with nine fuzzy subsets as extremely low (EL), lowest (LT), lower (LR), low (L), medium (M), high (H), higher (HR), highest (HT) and extremely high (EH) [20]. These input and output membership functions are shown in Figures 3 and 4 respectively. Table 3 exhibits different input parameters and outputs considered in this example along with their maximum and minimum values which are treated as the universes of discourse for their subsequent fuzzification.

Table 1 Ring spinning process parameters and their levels for example 1 [16]

Process parameter	Coded level		
	-1	0	1
Spindle speed	15000	17000	19000
Yarn TM	3.7	3.9	4.1
Roving TM	1.1	1.3	1.5

Table 2 Experimental data based on Box-Behnken design plan for example 1 [16]

Run No.	Process parameter			Response					
	Spindle speed	Yarn TM	Roving TM	BR	SS	IR	BE	HI	IM
1	0	1	1	5.7	17.09	8.31	3.53	5.51	122
2	-1	-1	0	4.4	15.61	9.11	3.97	5.85	95
3	1	0	1	11.6	15.93	8.39	3.3	5.71	128
4	1	1	0	10.9	16.35	8.93	3.59	5.67	99
5	1	0	-1	13.5	15.87	9.25	4.19	5.85	108
6	0	0	0	6.13	16.09	8.63	3.67	5.81	83
7	0	1	-1	5.99	16.27	8.91	4.39	5.74	103
8	-1	0	1	4.11	15.83	8.57	3.41	5.59	113
9	0	0	0	6.32	16.13	8.69	3.71	5.75	78
10	-1	0	-1	4.31	15.97	9.09	4.43	5.79	98
11	0	-1	1	7.99	15.75	8.47	3.49	5.91	125
12	-1	1	0	4.09	16.07	8.79	4.19	5.73	81
13	0	0	0	6.51	16.19	8.61	3.81	5.77	85
14	1	-1	0	15.8	15.43	8.87	3.47	6.11	93
15	0	-1	-1	9.13	15.51	9.03	4.41	5.87	119

Linguistic statements in the form of fuzzy rules characterize the relationship between the inputs and outputs in a fuzzy model [21]. The expressions representing the relationships between the three ring spinning process parameters and six considered yarn characteristics are provided in Table 4. These developed rules are also represented in Figure 5 as derived from the rule viewer of the fuzzy tool box (MATLAB R2014b). In this figure, the rows represent the corresponding fuzzy rules developed exhibiting the relationships between the ring spinning process parameters and yarn characteristics. Thus, for the 15 experimental runs, 15 fuzzy rules are developed. In this rule viewer, the first three columns show the input process parameters and the remaining six columns express the output yarn characteristics. The location of each triangle in the rule viewer represents the fuzzy MF and the height of the darkened area denotes the fuzzy membership value for the corresponding fuzzy set [22]. From Figure 5, it can clearly be revealed that when spindle speed = 17000 rpm, yarn TM = 4.1 and roving TM = 1.5, the corresponding yarn characteristics are expected to have values as BR = 5.55, SS = 17 g/tex, IR = 8.35, BE = 3.43%, HI = 5.53 and IM = 122. From the experimental observations as presented in Table 2, it can be identified that at this process parameter combination, the six yarn characteristics have values as BR = 5.7, SS = 17.09 g/tex, IR = 8.31, BE = 3.53%, HI = 5.51 and IM = 122. Thus, there is a great congruence between the actual observations and outputs predicted from the fuzzy logic model for this ring spinning process. In Figure 6, detailed comparisons between the experimental and predicted values for all the six yarn characteristics are provided.

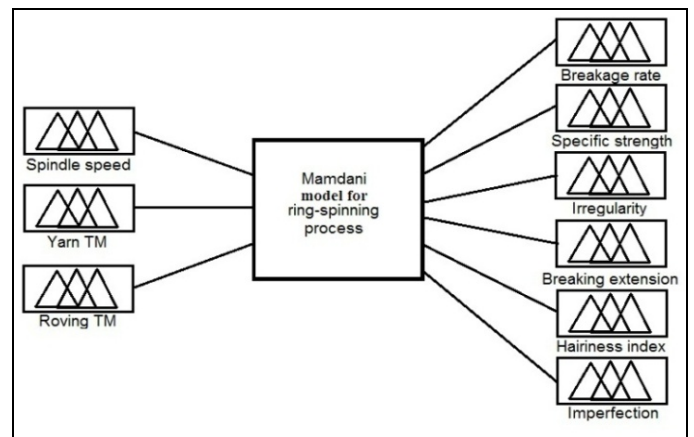


Figure 2. Model for inputs and outputs in example 1 based on fuzzy inference system

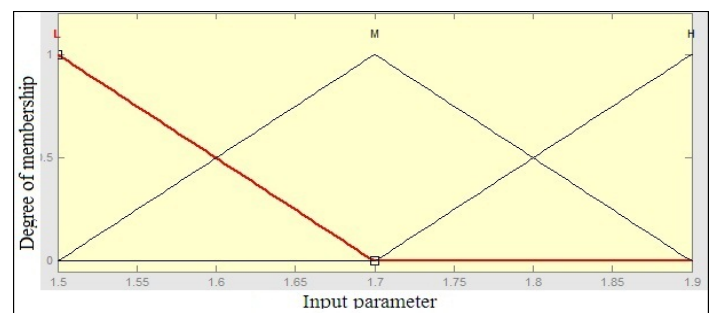


Figure 3 Fuzzification of input process parameters

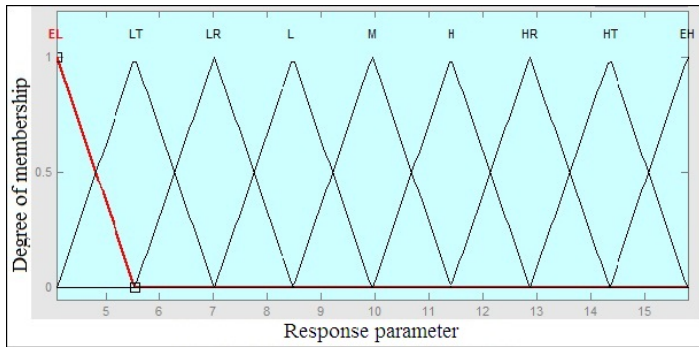


Figure 4 Fuzzification of yarn characteristics (responses)

Table 3 Inputs and outputs to fuzzy logic modelling for example 1

Process parameter/ Response	Input/ Output	Minimum value	Maximum value
Spindle speed	Input	15000	19000
Yarn TM	Input	3.7	4.1
Roving TM	Input	1.1	1.5
Breakage rate	Output	4.09	15.8
Specific strength	Output	15.43	17.09
Irregularity	Output	8.31	9.25
Breaking extension	Output	3.3	4.3
Hairiness index	Output	5.51	6.11
Imperfection	Output	78	128

Table 4 Fuzzy expressions for inputs and outputs for example 1

Run No.	IF					THEN					
	Spindle speed	Connection	Yarn TM	Connection	Roving TM	BR	SS	YI	BE	HI	IR
1	M	and	H	and	H	LT	EH	EL	LT	EL	HT
2	L	and	L	and	M	EL	EL	HT	H	H	L
3	H	and	M	and	H	H	LT	EL	EL	L	EH
4	H	and	H	and	M	H	M	H	LR	LR	L
5	H	and	M	and	L	HT	LR	EH	HT	H	H
6	M	and	M	and	M	LT	L	L	LR	M	EL
7	M	and	H	and	L	LT	M	H	EH	L	M
8	L	and	M	and	H	EL	LR	LR	EL	LT	HR
9	M	and	M	and	M	LT	L	L	L	L	EL
10	L	and	M	and	L	EL	LR	HT	EH	M	L
11	M	and	L	and	H	LR	LT	LT	LT	HR	EH
12	L	and	H	and	M	EL	L	M	HT	L	EL
13	M	and	M	and	M	LT	M	LR	M	L	LT
14	H	and	L	and	M	EH	EL	H	LT	EH	LR
15	M	and	L	and	L	L	EL	HR	EH	H	HT

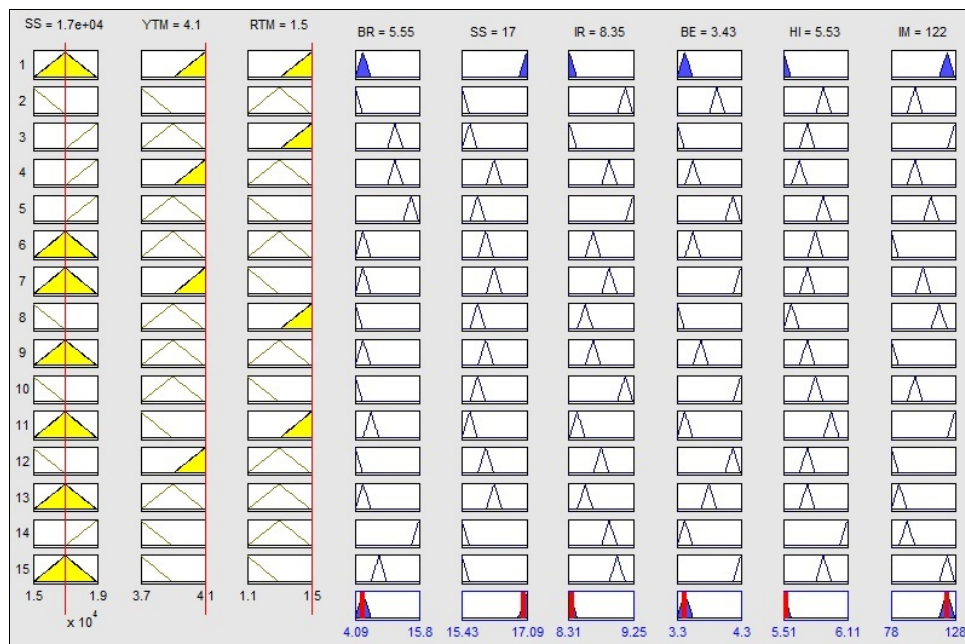


Figure 5 Developed rule viewer for example 1

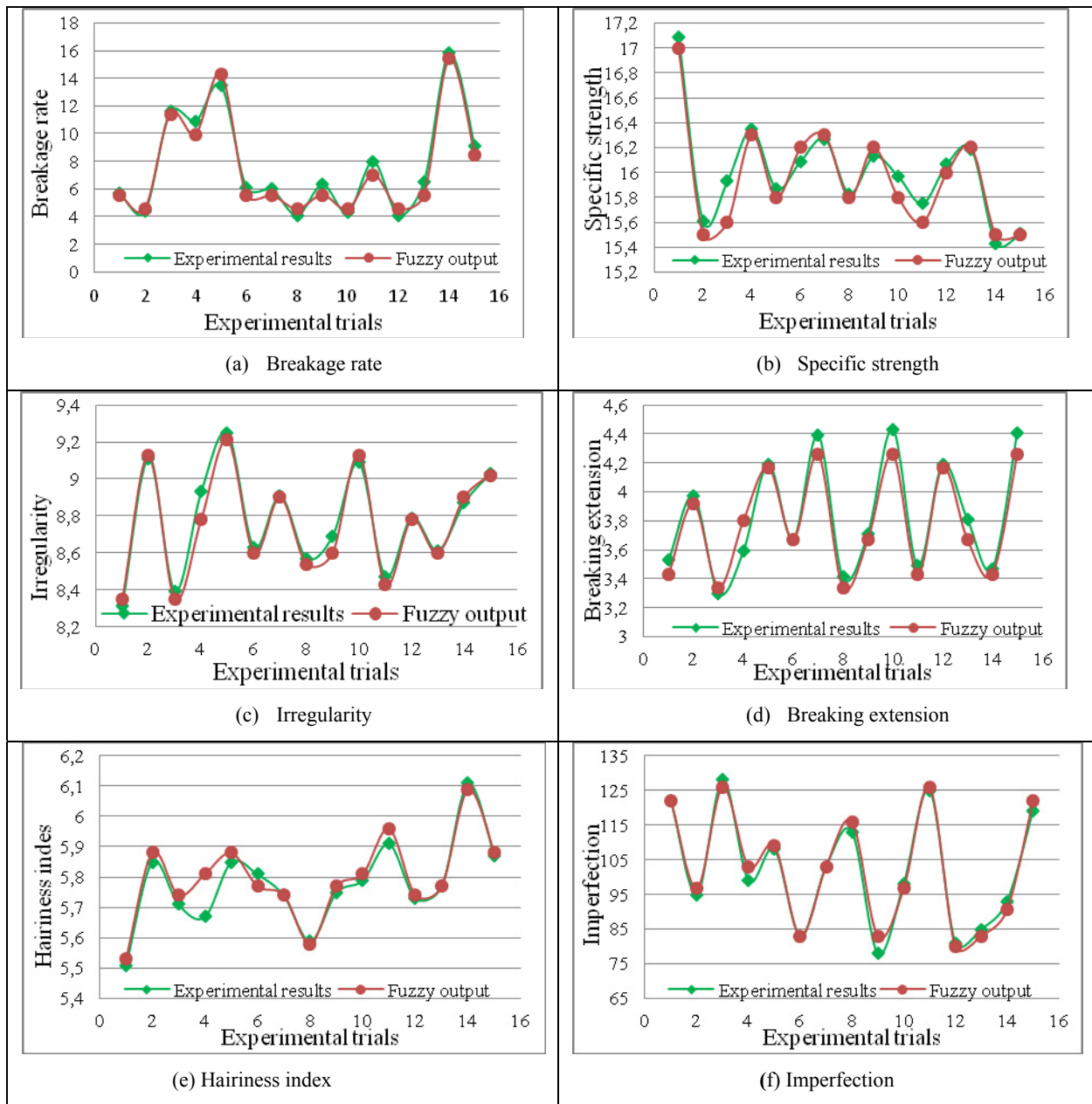


Figure 6 Comparisons between experimental results and fuzzy predictions for example 1

The effects of the three ring spinning process parameters, i.e. spindle speed, yarn TM and roving TM on the six considered yarn characteristics, e.g. breakage rate per 100 spindle per hour, specific strength, irregularity, breaking extension, hairiness index and imperfections per km are analyzed through Figures 7-12. These interaction graphs describing the effects of different input process parameters on yarn characteristics are developed using Minitab R17 software. The influences of spindle speed, roving TM and yarn TM on yarn breakage rate are first exhibited in Figure 7. It can be observed that with the increase in spindle speed, yarn breakage rate also increases. But, it decreases with increase in yarn TM. With the increment in spindle speed, spinning tension shows an increasing trend which causes more yarn breakages. More yarn twist is responsible for better gripping of fibres in the final yarn causing reduction in the number of yarn

breakages. On the other hand, as shown in Figure 7(b), when roving TM increases, the cotton fibres in the drafting zone are better controlled preventing unnecessary movement of the floating fibres which ultimately causes a reduction in yarn breakage rate. It becomes quite obvious from Figure 7(c) that an increment in yarn twist level causes yarn breakage rate to decrease as more yarn twist provides the requisite spinning tension while minimizing the number of yarn breakages. Figure 8(a) depicts the variation of yarn specific strength with respect to spindle speed at varying values of yarn TM while keeping roving TM constant at 1.3. It can be noticed that specific strength first increases with increasing values of spindle speed. Then, after reaching its maximum value at spindle speed of 17000 rpm, it shows a decreasing trend pattern. On the other hand, higher yarn TM provides higher specific strength which becomes also

observed from Figure 8(c). In Figure 8(b), it is clearly revealed that at varying values of spindle speed, roving TM has almost no effect on the specific strength. The influences of different ring spinning process parameters on yarn irregularity are portrayed in Figure 9. At different values of yarn TM, yarn irregularity starts decreasing with the increment in spindle speed and after reaching its minimum at 17000 rpm of spindle speed, its value shows an increasing trend, as shown in Figure 9(a). From Figure 9(b), it can be observed that at varying values of spindle speed, yarn irregularity is reduced with the increment in the value of roving TM. Similarly, yarn irregularity almost decreases with increasing values of yarn TM, as noticed from Figure 9(c). When the variations of breaking extension are plotted with the changing values of the three ring spinning process parameters, it can be propounded from Figure 10(a) that breaking extension shows a decreasing trend with increasing spindle speed at different values of yarn TM. The similar type of variation is also observed when the influence of roving TM on breaking extension is plotted in Figure 10(b) for different values of spindle speed. With the increase in roving TM, breaking extension thus decreases. Figure 10(c) exhibits that with the increment in the value of yarn TM, breaking extension remains almost unaltered at different values of roving TM. Similarly, the effects of the three considered ring spinning process parameters on yarn hairiness index are graphically presented in Figure 11. It can clearly be observed in Figure 11(a) that for low yarn TM, hairiness index gradually increases with spindle speed. But, for moderate to high yarn TM values, hairiness index shows an almost unchanged pattern with increasing values of spindle speed. Figure 11(b) reveals that for low to moderate roving TM and at different spindle speeds, yarn hairiness index remains steady and for higher roving TM values, it goes on decreasing.

From Figure 11(c), it can be noticed that for increasing values of yarn TM, yarn hairiness index exhibits a decreasing trend pattern at different settings of roving TM. Figure 12 presents the effects of the three process parameters on yarn imperfection. It can be noticed from Figure 12(a) that for low to moderate spindle speed, intermediate values of roving TM and yarn TM, yarn imperfection first decreases, and for moderate to high spindle speed, its value then starts increasing. It is thus always recommended to set the spindle speed, roving TM and yarn TM at their moderate values so as to minimize the number of yarn imperfections. Figure 12(b) also confirms the fact that yarn imperfection can really be minimized at the intermediate settings of the three process parameters. Figure 12(c) depicts the variations in yarn imperfection with respect to yarn TM at different settings of roving TM. It can again be observed that minimum imperfection can only be obtained at intermediate values of yarn TM and roving TM. The reasons behind the variations of the six yarn characteristics with respect to the changing values of the three ring spinning process parameters were well studied by Hasanuzzaman et al. [16], and the patterns observed by Hasanuzzaman et al. [16] for the variations are in close agreement with those as attained in this paper based on the interaction graphs. Based on these interaction plots, it can be concluded that for having the most desired values of all the considered yarn characteristics, an optimal setting of various ring spinning process parameters as spindle speed = 17000 rpm, roving TM = 1.3 and yarn TM = 3.9 is to be maintained. For the same process, Hasanuzzaman et al. [16] recommended a parametric mix as spindle speed = 17000 rpm, roving TM = 1.3 and yarn TM = 4.1.

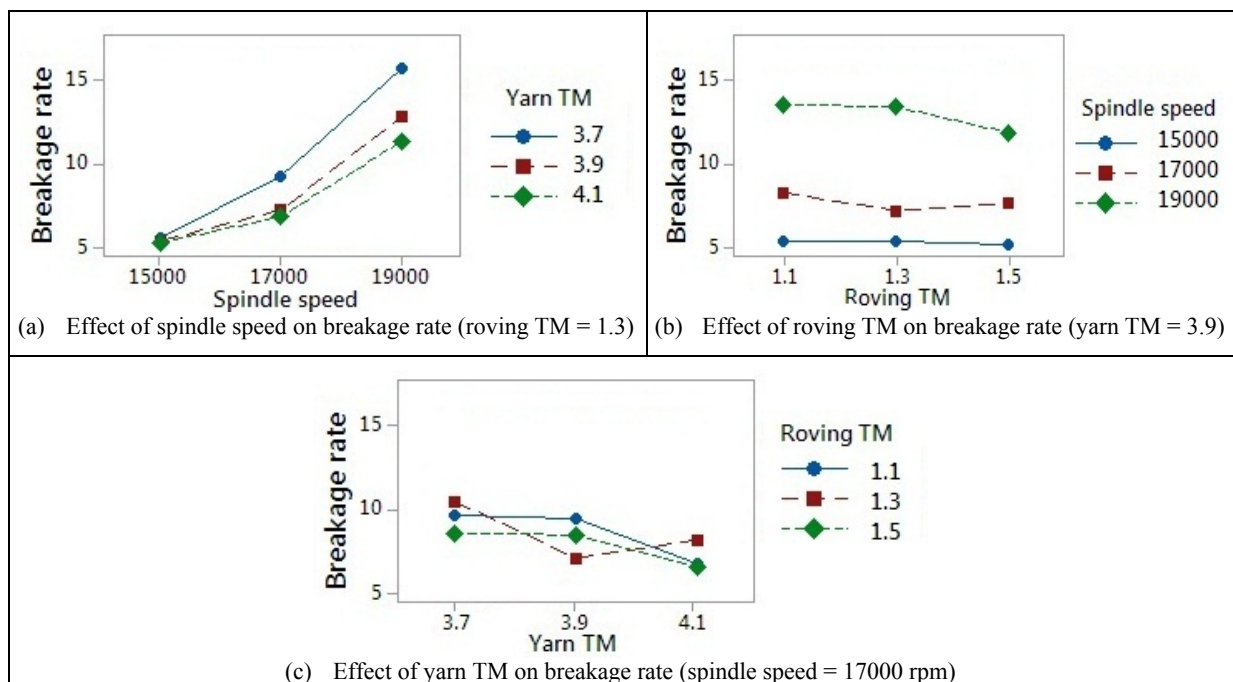


Figure 7 Effects of ring spinning process parameters on breakage rate for example 1

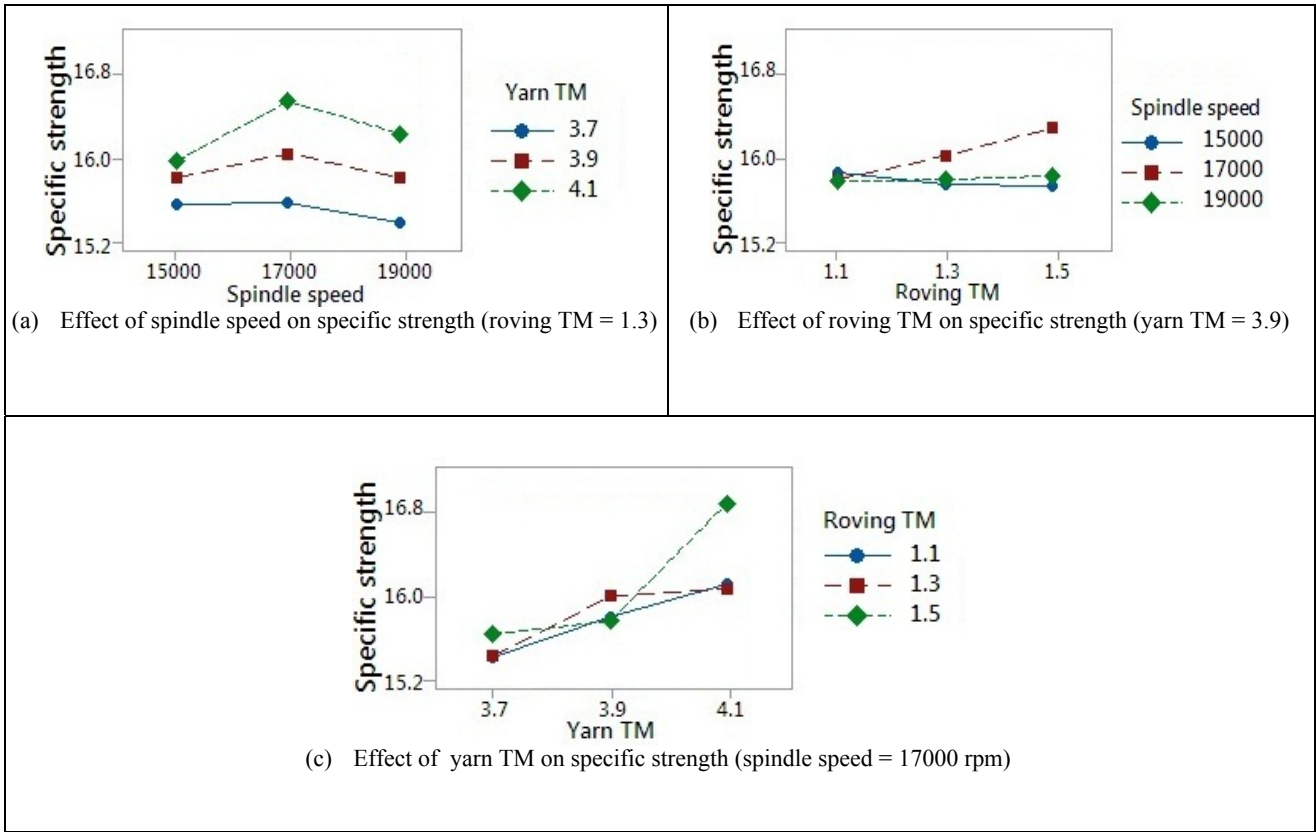


Figure 8 Effects of ring spinning process parameters on specific strength for example 1

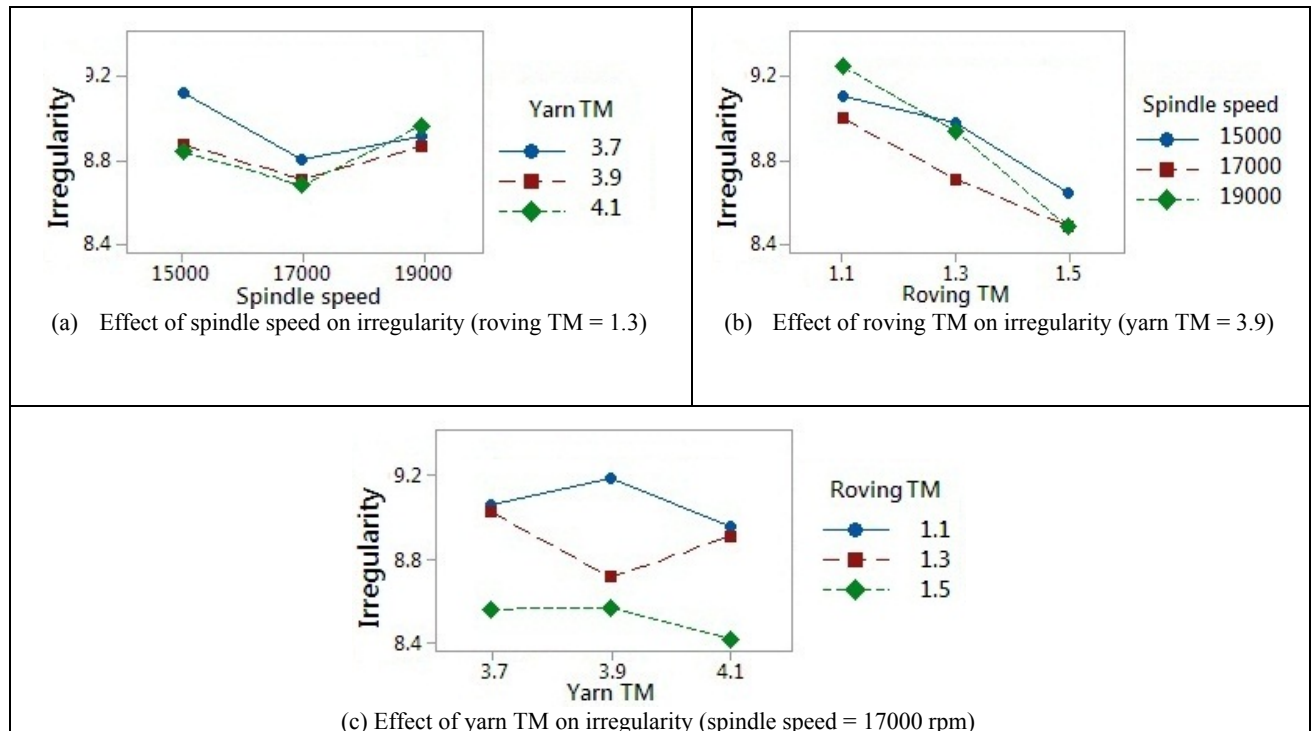


Figure 9 Effects of ring spinning process parameters on irregularity for example 1

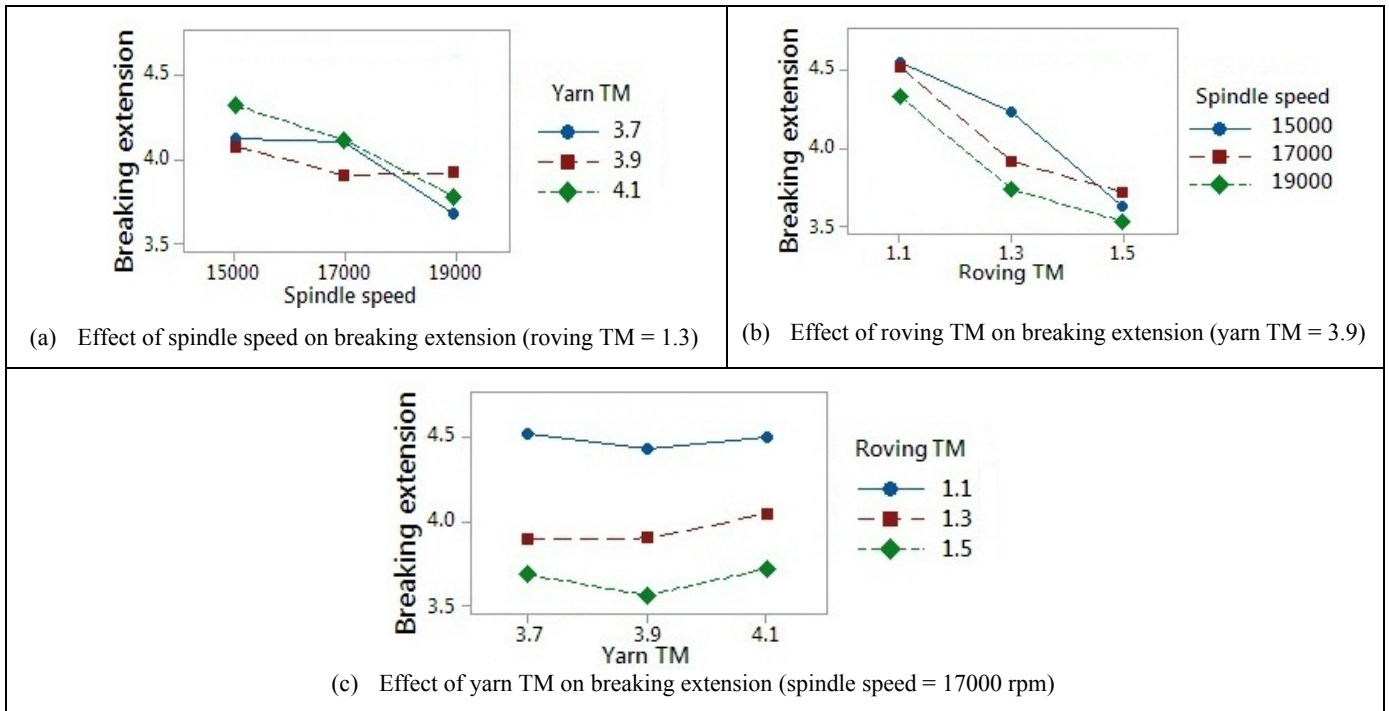


Figure 10. Effects of ring spinning process parameters on breaking extension

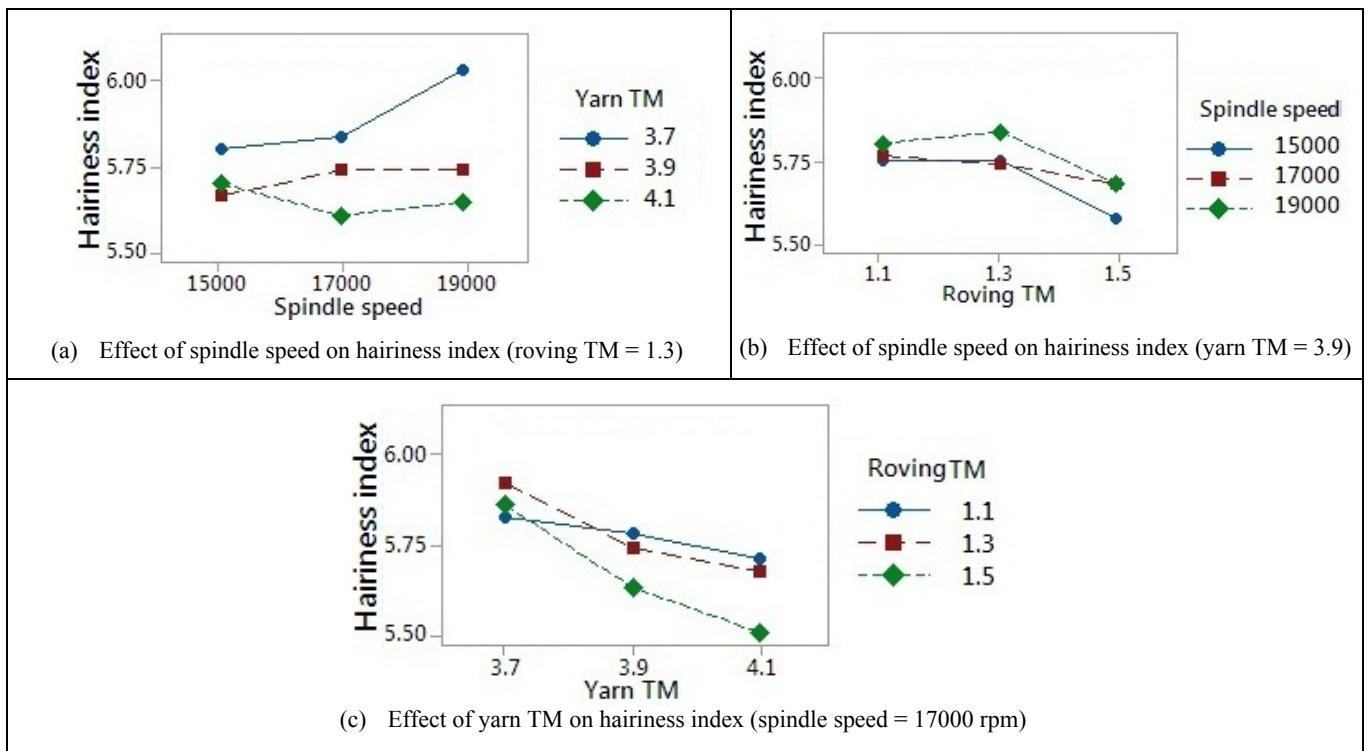


Figure 11 Effects of ring spinning process parameters on hairiness index

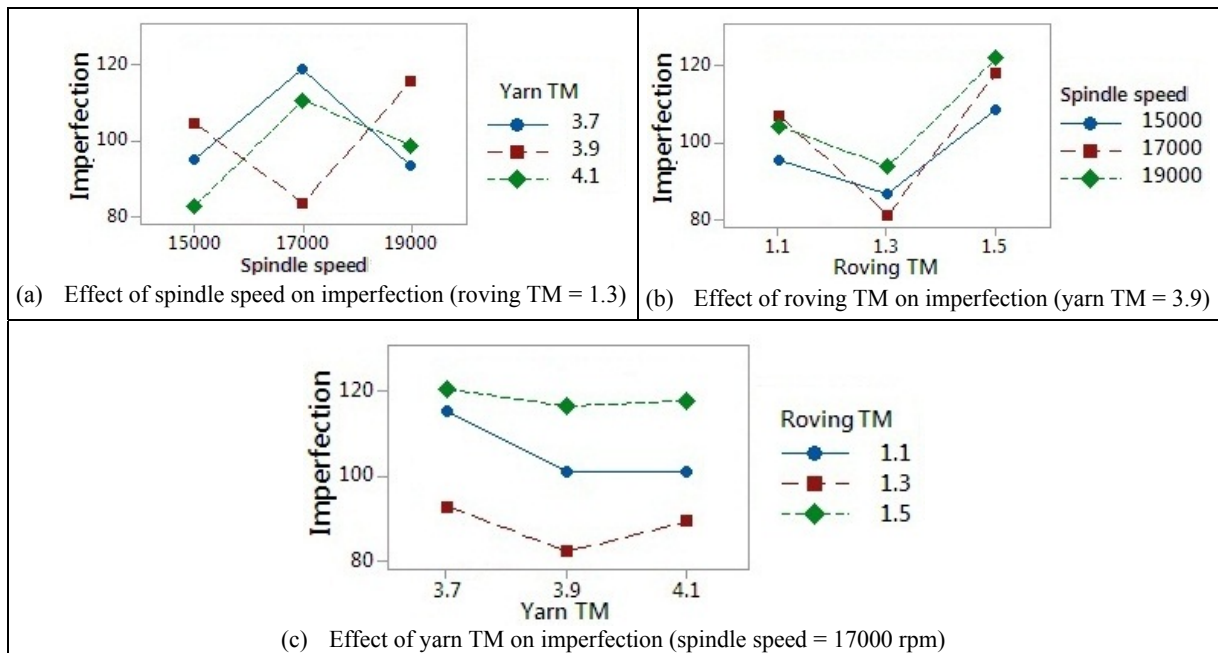


Figure 12 Effects of ring spinning process parameters on imperfection

Example 2

In this example, the observations of Ishtiaque et al. [5] are considered for fuzzy-based modelling of a ring spinning process. Using Box-Behnken experimental design plan, Ishtiaque et al. [5] investigated the effects of three ring frame parameters, i.e. spindle speed (in rpm), top roller pressure (in kg/cm²) and traveller mass (ISO No.) on six yarn quality characteristics, i.e. end breakage rate (EBR) (in number of end breaks/100 spindle/h), IR (in U%), HI, IM, tenacity (T) (in g/tex) and elongation at break (EB) (in %). Each of those ring spinning process parameters was set at three different operating levels, as provided in Table 4. On the other hand, Table 5 exhibits the results of 15 experimental runs based on three-variable Box-Behnken design plan.

Now, in order to develop the corresponding fuzzy logic model for this ring spinning process, the three process parameters are treated as the input variables, whereas, the six yarn characteristics are considered as the output variables. The schema of this three-input-six-output fuzzy model is depicted in Figure 13. Based on the triangular fuzzy MFs, as shown in Figures 3 and 4, all the input and output variables are first fuzzified having three and nine fuzzy subsets respectively. Now, the relationships between the input and output variables are linguistically developed in Table 6. Based on these linguistic expressions for 15 experimental runs, the corresponding fuzzy rule viewer is also generated in MATLAB R2014b (not shown here due to scarcity of space). This rule viewer depicts that when spindle speed = 13000 rpm, top roller pressure = 2 kg/cm² and traveller mass = 45 (ISO No.), the values of the considered yarn characteristics are predicated as EBR = 5.8, IR = 9.33%, HI = 6.02, IM = 131, T = 15.2 g/tex and EB = 4.35%. The experimental data of Table 5 exhibit that at this particular

parametric setting, the values of the six yarn characteristics are EBR = 6, IR = 9.28%, HI = 6.03, IM = 128, T = 15.17 g/tex and EB = 4.30%. Thus, it can be concluded that there is a high degree of agreement between the observed data and those as envisaged from the developed fuzzy logic model for this ring spinning process. Figure 14 represents detailed comparisons between the actual observations and the predicted yarn characteristics.

Table 4 Process parameters with their actual and coded values for example 2 [5]

Process parameter	Coded value		
	-1	0	1
Spindle speed	13000	15000	17000
Top roller pressure	2.0	2.25	2.5
Traveller mass	40	45	50

The variations of the considered yarn quality characteristics with changing values of the three ring spinning process parameters, i.e. spindle speed, top roller pressure and traveller mass are graphically represented through Figures 15-20. In Figure 15(a), it can be observed that for varying values of top roller pressure, yarn end breakage rate increases with spindle speed. An increase in spindle speed causes spinning tension to exceed its threshold limit, resulting in more number of end breakages. From Figure 15(b), it can be noticed that for higher spindle speed, breakage rate increases with the increase in traveller mass, but for lower values of spindle speed, it decreases with traveller mass. For this ring spinning process, it is always recommended to set the considered process parameters at their intermediate levels in order to minimize end breakage rate, as depicted in Figure 15(c). From Figures 16(a)-(c), it can be revealed that yarn irregularity slightly increases with spindle speed, whereas, it exhibits

Table 5 Experimental results for example 2 [5]

Exp. No.	Process parameter			Response					
	Spindle speed	Top roller pressure	Traveller mass	EBR	IR	HI	IM	T	EB
1	-1	-1	0	6.0	9.28	6.03	128	15.17	4.30
2	-1	1	0	4.7	8.62	6.14	85	16.21	4.21
3	1	-1	0	14.6	9.41	5.88	137	16.15	3.49
4	1	1	0	13.4	8.73	5.94	98	16.32	3.41
5	-1	0	-1	5.8	9.34	6.32	133	15.40	4.49
6	-1	0	1	4.3	8.72	5.79	121	16.08	4.20
7	1	0	-1	13.8	9.44	6.28	138	15.09	3.58
8	1	0	1	16.3	8.87	5.71	113	16.71	3.38
9	0	-1	-1	7.1	9.14	5.93	105	16.17	3.57
10	0	-1	1	6.5	9.05	5.60	97	16.52	3.38
11	0	1	-1	6.2	8.78	5.67	90	16.63	3.41
12	0	1	1	5.2	8.59	5.51	89	16.80	3.39
13	0	0	0	6.9	9.19	5.79	111	16.31	3.35
14	0	0	0	7.3	9.23	5.58	115	16.08	3.40
15	0	0	0	8.1	9.09	5.71	114	16.37	3.42

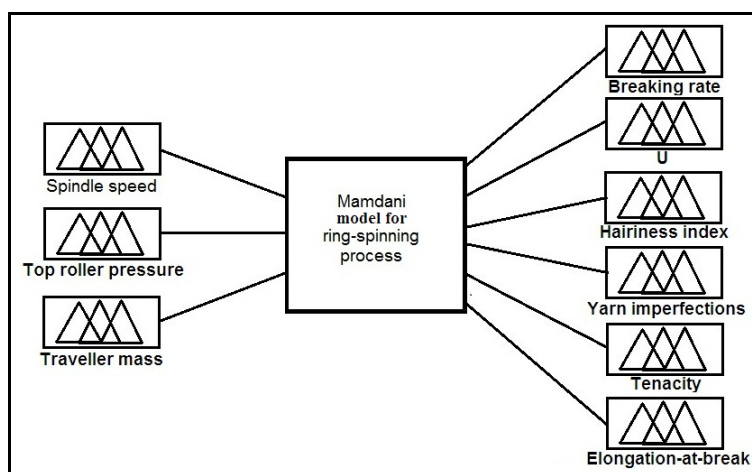


Figure 13 Three-input-six-output fuzzy model for example 2

Table 6 Fuzzy relations between the input and output variables for example 2

Exp. No.	IF					THEN					
	Spindle speed	Connection	Top roller pressure	Connection	Traveller mass	EBR	IR	HI	IM	T	EB
1	L	and	L	and	M	LT	HT	H	HT	EL	HT
2	L	and	H	and	M	EL	EL	HT	EL	H	HR
3	H	and	L	and	M	HT	EH	M	EH	H	LT
4	H	and	H	and	M	HR	LT	M	LR	HR	EL
5	L	and	M	and	L	LT	HT	EH	EH	LT	EH
6	L	and	M	and	H	EL	LT	L	HR	H	HR
7	H	and	M	and	L	HT	EH	EH	EH	EL	LT
8	H	and	M	and	H	EH	LR	LR	M	EH	EL
9	M	and	L	and	L	LR	H	M	L	H	LT
10	M	and	L	and	H	LT	M	LT	LR	HT	EL
11	M	and	H	and	L	LT	LR	LT	EL	EH	EL
12	M	and	H	and	H	EL	EL	EL	EL	EH	EL
13	M	and	M	and	M	LT	HR	L	M	HR	EL
14	M	and	M	and	M	LR	HR	EL	H	H	EL
15	M	and	M	and	M	LR	H	LR	M	HR	EL

decreasing trend patterns with increasing values of traveller mass and top roller pressure. When the variations in hairiness index are plotted in Figures 17(a)-(c) with respect to different values of the considered ring spinning process parameters, it can be propounded that minimum hairiness index can only be achieved at moderate values of spindle speed, traveller mass and top roller pressure. The effects of the process parameters on yarn imperfection are portrayed in Figures 18(a)-(c). For higher values of spindle speed, yarn imperfection increases. From Figure 18(b), it can be noticed that yarn imperfection is minimized at the intermediate values of traveller mass and top roller pressure. Figure 18(c) also confirms these observations.

When the variations in tenacity with respect the changing values of spindle speed, top roller pressure and traveller mass are

plotted in Figures 19(a)-(c), it is observed that with increment in spindle speed, yarn tenacity first increases, and after reaching its maximum value at the intermediate spindle speed, it exhibits a decreasing trend pattern. On the other hand, tenacity gradually increases with traveller mass. With respect to the varying values of top roller pressure, it first decreases and then shows an increasing trend pattern. At different values of top roller pressure, at first, elongation at break decreases with respect to spindle speed and after arriving at its minimum value at intermediate spindle speed, it remains almost steady. Elongation at break almost shows a linearly decreasing trend with increasing values of traveller mass. The effects of top roller pressure on elongation at break at different values of traveller mass are shown in Figure 20(c). Now, based on the detailed analysis of

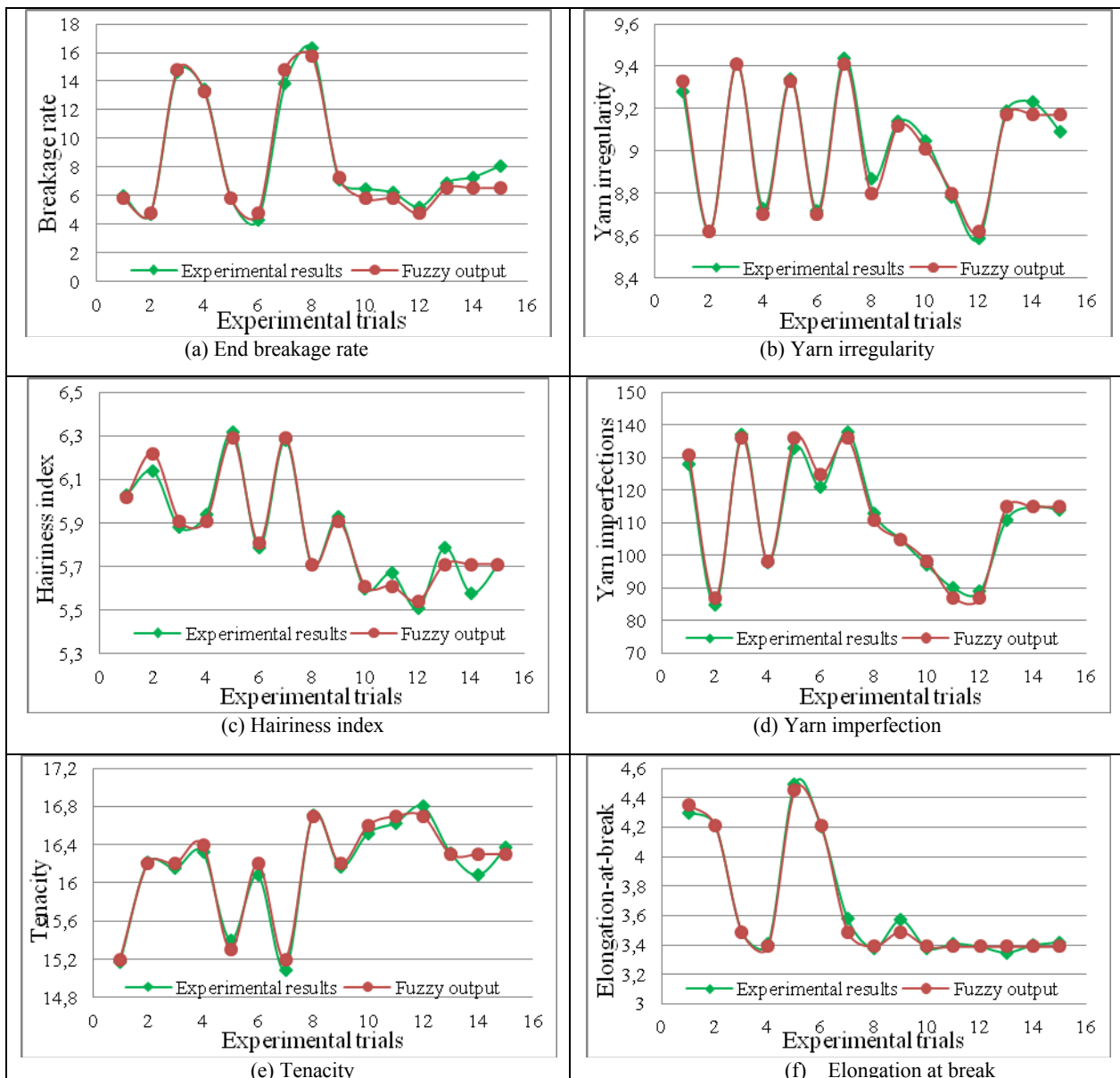


Figure 14 Comparisons between experimental data and fuzzy predicted values for example 2

the developed interaction plots, it can be concluded that in order to achieve the optimal values of the six yarn characteristics, it is always recommended to set the ring spinning process parameters at their intermediate combinations, i.e. spindle speed = 15000 rpm, top roller pressure = 2.25 kg/cm² and traveller mass = 45 (ISO No.). On the other hand, Ishtiaque et al. [5] determined the optimal settings of the three process parameters as spindle speed

= 15000 rpm, top roller pressure = 2.50 kg/cm² and traveller mass = 50 (ISO No.). It was also suggested that for higher spindle speed of 17000 rpm, the traveller mass would be chosen as 40 (ISO No.). Thus, there exists a close congruence between the parametric settings as observed based on the interaction plots and those derived by the past researchers.

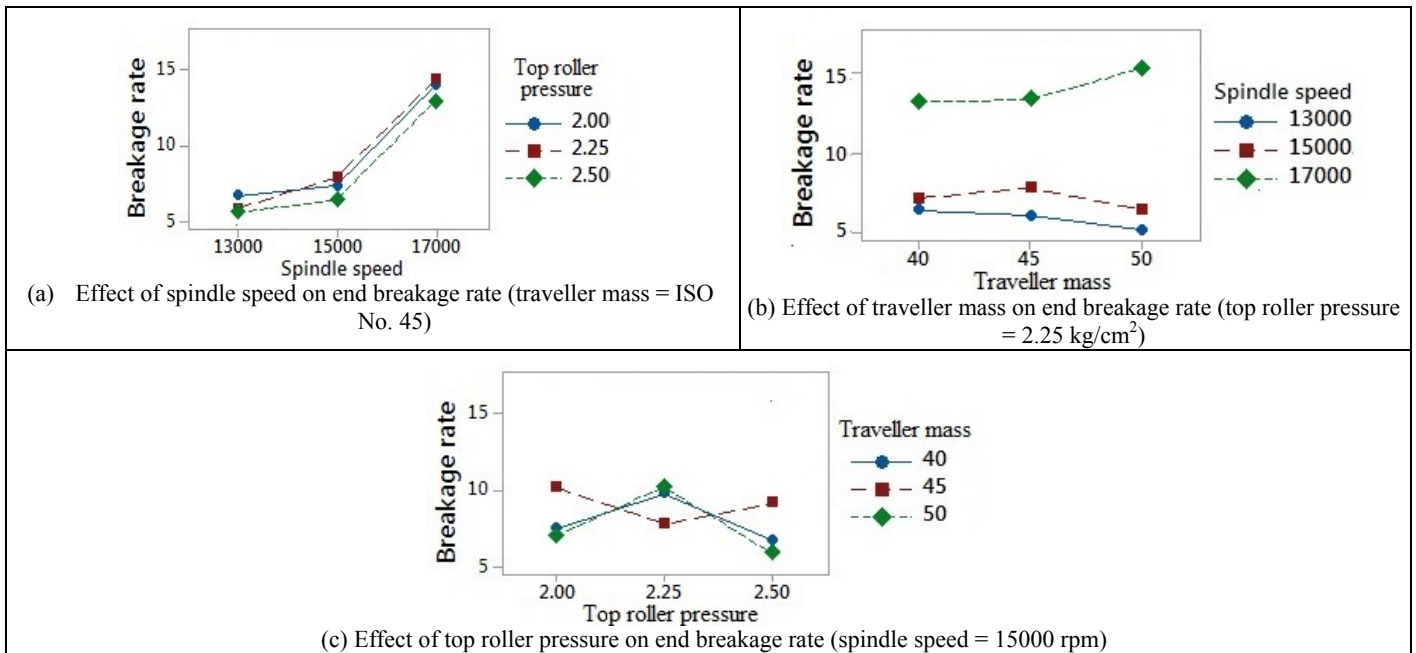


Figure 15 Effects of ring spinning process on end breakage rate for example 2

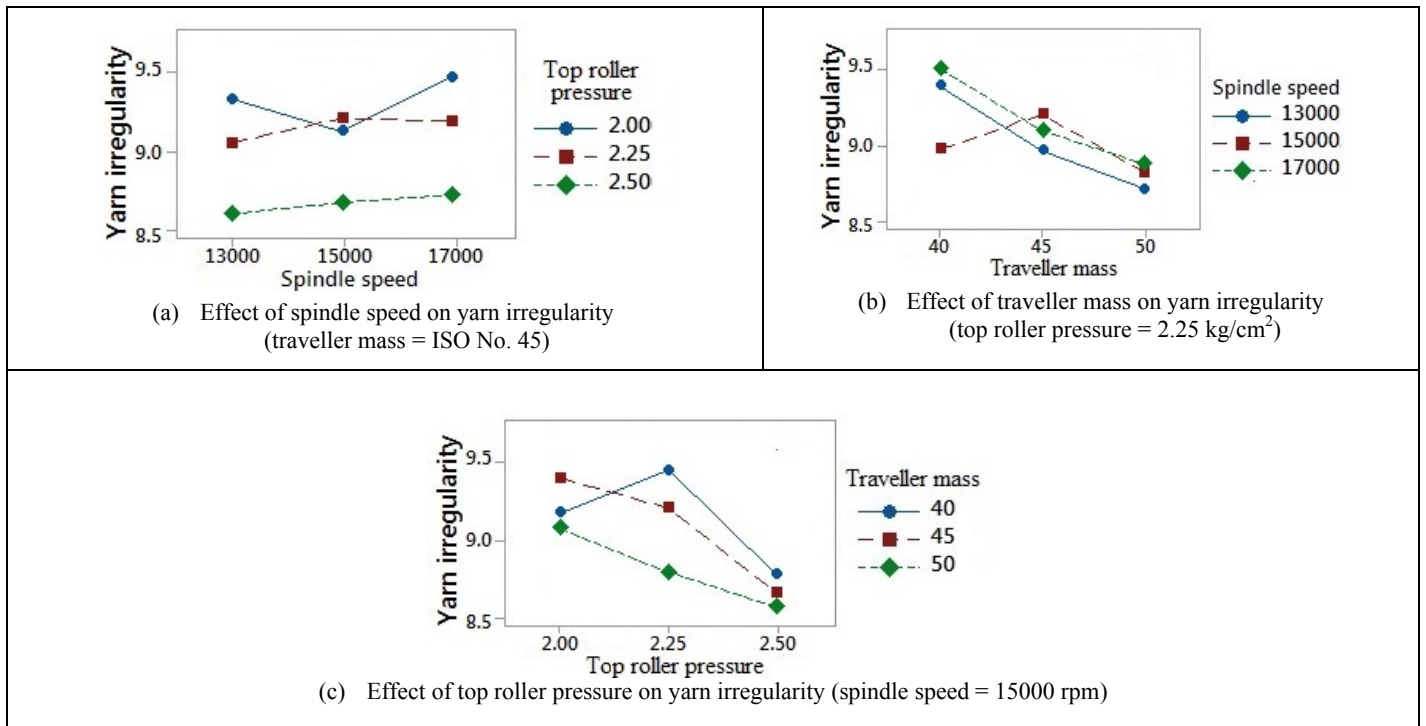


Figure 16 Effects of ring spinning process on yarn irregularity for example 2

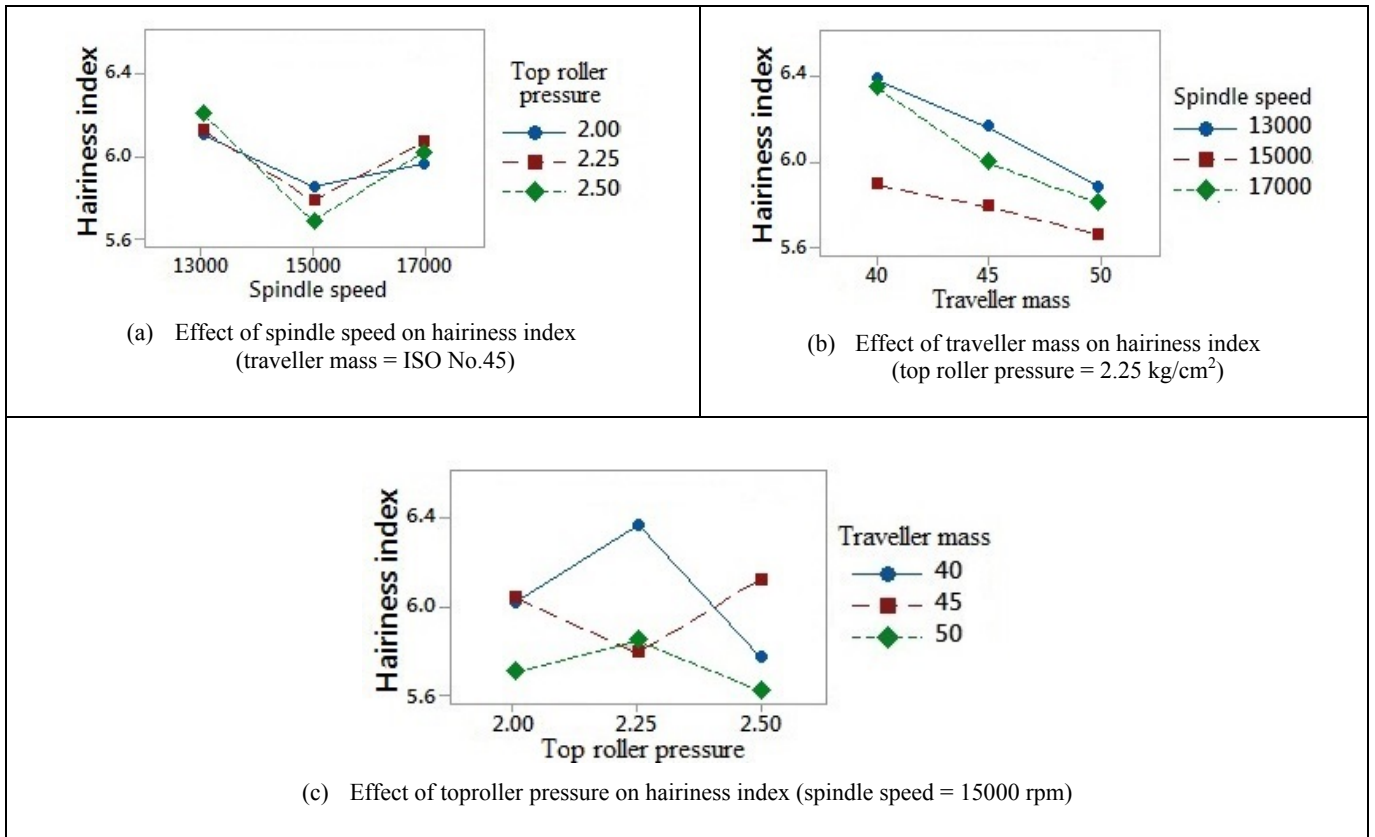


Figure 17 Effects of ring spinning process on hairiness index for example 2

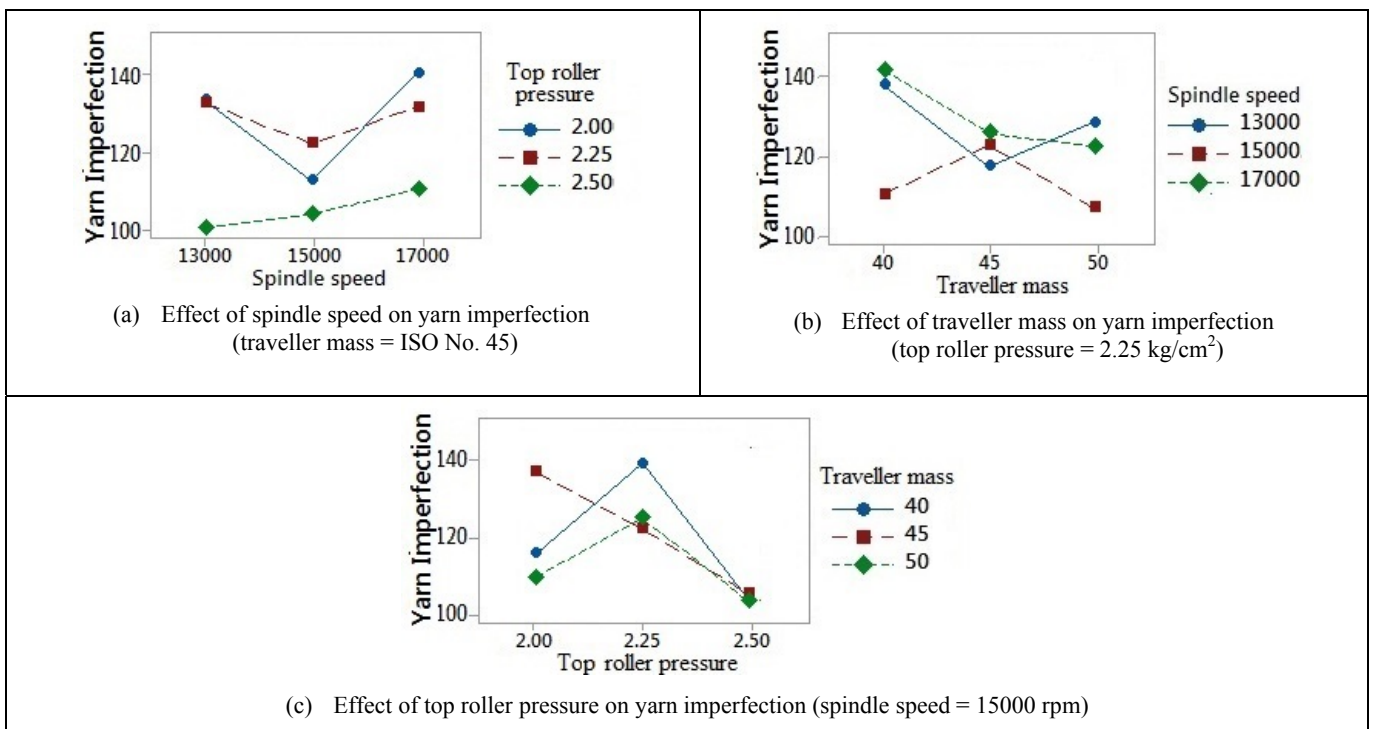


Figure 18 Effects of ring spinning process on yarn imperfection for example 2

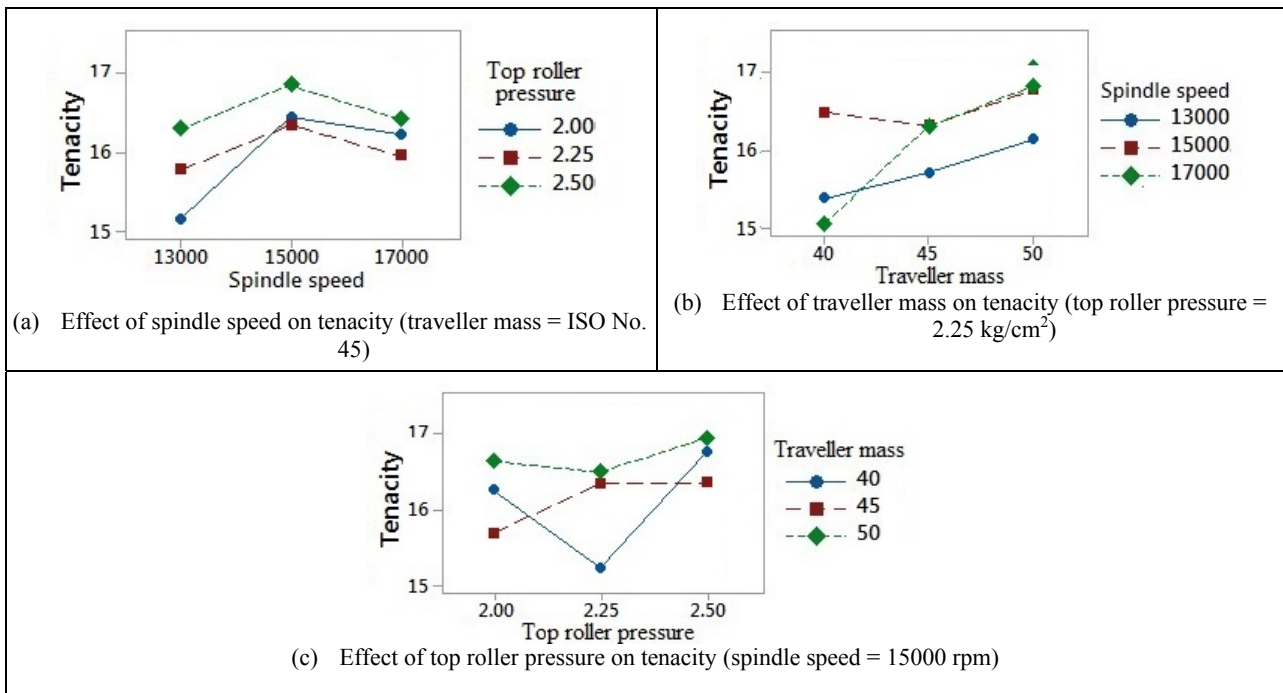


Figure 19 Effects of ring spinning process on tenacity for example 2

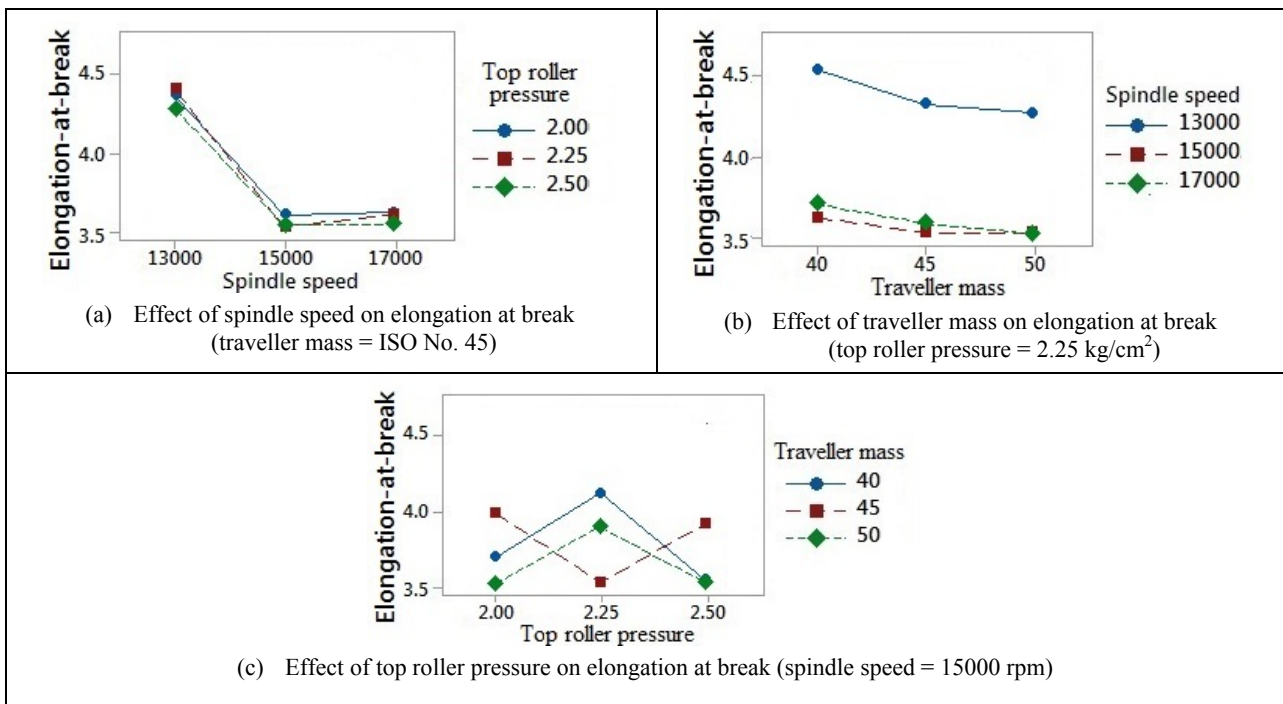


Figure 20 Effects of ring spinning process on elongation at break for example 2

5. CONCLUSIONS

In this paper, based on the experimental observations of the past researchers, two ring spinning processes are considered so as to model them using fuzzy logic. The related fuzzy relations are subsequently developed portraying the associations between different ring spinning process parameters and yarn quality

characteristics. It is observed that the response values as predicted from the fuzzy models are in close congruence with the observed experimental results. These models can thus be able to act as a guide to envisage the tentative values of different yarn characteristics based on a combination of ring spinning process parameters. The interaction plots exhibiting the influences of the input parameters on the output variables in the ring spinning

processes help in identifying the optimal parametric settings so as to attain the most desired yarn properties. Based on the derived results, it can be recommended to operate a ring spinning process with all its controllable parameters set at their moderate levels. The concept of fuzzy logic can thus be applied to any intermediate process in a textile industry to achieve the maximum profit with better quality of products. Although, in this paper, two ring spinning processes are modelled based on fuzzy logic to guide the cotton spinning personnel in setting the most preferred combination of process parameters for having the desired yarn characteristics, it can also be officiously extended to manufacturing of yarns from other fibrous materials.

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