Part A: English Edition

Journal of Textiles and Polymers

Vol. 9, No. 3, 37-44, July 2021

http://dx.doi.org/10.48302/jtp.2021.136077

ORIGINAL PAPER

Maximum Negative Poisson's Ratio of Double-Core Helical Auxetic Yarns Under Uniaxial Loading: A Study on the Effect of Structural Parameters via Full Factorial Experimental Design Method

Milad Razbin, Mostafa Jamshidi Avanaki*, Ali Asghar Asghariyan Jeddi, and Hadi Dabiryan

Received: 30 December 2020, Accepted: 9 May 2021

***Abstract*- Auxetic textiles have been attracted the attention of many researchers due to their enhanced mechanical behavior during loading condition. The developed Double-core helical auxetic yarn (DC-HAY) is a structural material with negative Poisson's ratio (NPR) behavior. It consists of two similar soft yarns with a higher diameter and a stiff yarn with a lower diameter. The stiff yarn has been twisted around the soft yarns, alternatively. In this paper, the effect of structural parameters including, the initial helical angle of wrap component with five levels, diameter ratio of components with three levels, and modulus ratio of components with two levels, on Poisson's ratio of DC-HAY, has been investigated through the full factorial experimental design method. SPSS software has been used for analyzing the results. The results showed that the highest maximum NPR belongs to the sample with the lowest initial helical angle, highest diameter ratio of components, and highest modulus ratio of components. Also, it has been found that all the main factors have a statistically significant effect on Poisson's ratio of DC-HAY at a 95% of confidence level.**

***Keywords*: double-core helical auxetic yarn (DC-HAY), negative Poisson's ratio (NPR), image processing, full factorial**

I. INTRODUCTION

Auxetic materials are metamaterials with interesting properties that do not exist in common materials. Such material expands laterally under tensile loading and contracts latterly under the compression loading. Compared to common materials, they exhibit high in-plane shear modulus, high indentation resistance, high fracture resistance and low crack propagation, synclastic curvature, strain dependable porosity, high energy absorption, etc. These extraordinary properties made them suit for application in the field of aerospace, automotive, biomedical, composites, military, sensors/actuators, and textiles [1]. Auxetic textiles are known as one of the most favorable structural materials for developing auxetic behavior due to their structural variability and high material adaptability. Auxetic textiles are in three main forms; fibers, yarns, and fabrics. These forms are using in various products for different purposes. For example, fiber or yarn forms of auxetic textiles can lock the textiles in position during the tensile loading of textile reinforced composites, and fabric form can reduce drag delivery according to swelling decreases during the wound healing [2]. Auxetic yarns, besides the simplicity of their production process, have several advantages over conventional ones. During the three past decades, many forms of auxetic yarns such as the helical auxetic yarn (HAY) [3], semi-auxetic yarn (SAY) [4], auxetic plied yarn (APY) [5], braided auxetic yarn (BAY) [6], interlaced-helical wrapping yarn (IHWY) [7], braided yarn with helical auxetic yarn [8], and double-core helical auxetic yarn (DC-HAY) [9], have been introduced by scholars. Hook *et al.* proposed the first auxetic yarn, namely the helical auxetic yarn (HAY), combined with one soft fat yarn as a core component and a stiff thin yarn, twisted around it, as a wrap component. When the HAY is under the uniaxial tensile loading, the wrap component dominates the core component and starts to get straight due to its higher young modulus. This kind of deformation leads to expansion transversely non-uniform under tensile

M. Razbin, A.A. Asghariyan Jeddi, and H. Dabiryan
Department of Textile Engineering, Amirkabir University of Technology, Tehran, Iran.

M. Jamshidi Avanaki
Faculty of Engineering, University of Guilan, Rasht, Iran.

Correspondence should be addressed to M. Jamshidi Avanaki
e-mail: m.jamshidi@guilan.ac.ir

loading and results in auxetic performance. This type of yarn also can be produced by the conventional method of spun-yarns [3]. Du *et al.* conducted a theoretical study to present a geometrical model for predicting the Poisson's ratio of HAY under various amounts of structure strain and understanding the auxetic performance of HAY. The diameter of components, Poisson's ratio of components, and the initial helical angle of the wrap component were considered as the input parameters of the model. In the model, the whole tensile process is divided into two regions according to a criterion called "critical strain". The critical strain is the strain of structure that wrap component gets fully straighten before getting any elongation. The predicted amounts of Poisson's ratio versus axial strain showed the same trend as the experimental ones, but the values obtained through the theoretical model were much higher than the experimental ones because of considering the geometrical effect solely. They also simulated the HAY through the ABAQUS software to investigate the structural parameters on Poisson's ratio of structure. Despite the similar results, the numerical values were closer to experimental ones due to considering both materials and geometrical effect [10,11]. Sibal and Rawal presented a theoretical model based on the energy minimization approach for predicting Poisson's ratio of the HAY during tensile loading. According to their proposed model, the potential elastic energy stored in each component has been divided into tensile, shear, bending, and torsion terms. Based on their conclusion, the auxetic effect occurs under a strain level at which the bending term tends to dominate over the tensile term. Also, a "balanced" HAY having the same initial helical angles of wrap component and core components can be developed at a defined level of axial tensile strain when the torsion term of energy is the same as that of the corresponding shear term. The comparison results between the predicted values and the ones related to the experimental works showed a good agreement [12]. Kwietniewski and Miedzinska performed a numerical study through ABAQUS software for investigating the effect of structural parameters on the tensile properties of HAY. The results of the comparison of the true stress-true strain curve between predicted and experimental values showed a good agreement [13]. Liu *et al.* conducted a theoretical work for studying the effect of structural parameters on the tensile properties of HAY. According to their studies, pressure and friction between the components of HAY exist during the deformation. They tried to present a rheological model to analyze the structuring effect on the tensile properties of HAY. The comparison results showed a good agreement with a correlation coefficient of higher than 0.97 between the predicted and experimental values [14]. Razbin *et al.* tried to modify Du's model by replacing a new criterion called "jamming strain" instead of "critical strain". According to their study, the wrap component forms a helix with a radius equals to its initial radius at the jamming strain. They also suggested a function instead of a constant representing the non-linear Poisson's ratio behavior of the core component. The results showed significant improvement in prediction [15]. The same research courses have been conducted for auxetic plied yarn [16-18], braided auxetic yarn [19,20].

The scholars are trying to understand the deformation behavior of auxetic yarns during the tensile loading using different methods. To the best knowledge of the authors, despite the available reports concerning the experimental, numerical, and theoretical studies for auxetic yarns in the literature, there is no work on the statistical analysis of these structures. In this work, we undertake an experimental investigation on the maximum negative Poisson's ratio (NPR) of DC-HAY statistically via the full factorial experimental design method.

II. EXPERIMENAL

A. Materials and Experimental Design

In this study, three same types of monofilament core yarns with different diameters and two different types of monofilament warp yarn with the same diameter have been selected to produce the DC-HAY. To specify the mechanical properties of components, a tensile test according to ASTM D3822-01 via a testing device (Instron 5566) under the constant rate of elongation at 200 mm/min and a gauge length of 250 mm was conducted. The specifications of

TABLE I
SPECIFICATIONS OF COMPONENTS

Component	Type	d (mm)	E (MPa)	σ_u (MPa)	ε_{rup} (%)	ν
Core-1	Rubber	3.85±0.21	0.92±0.06	1.81±1.51	197.65±3.10	0.49
Core-2	Rubber	5.72±0.19	1.24±0.18	1.77±0.12	142.47±2.14	0.49
Core-3	Rubber	8.62±0.32	1.12±0.11	1.68±0.10	160.18±1.98	0.49
Wrap-1	Nylon 6	0.500±0.00	1667.53±2.14	414.23±3.49	29.31±1.41	0.42
Wrap-2	Copper	0.500±0.00	5060.34±4.10	273.32±1.37	44.25±0.50	0.36

TABLE II
EXPERIMENTAL DESIGN

Sample	Core yarn	Wrap yarn	θ_{actual} (degree)	d_c/d_w (mm/mm)	E_w/E_c (MPa/MPa)
A-1	Core-1	Wrap-1	15.16±0.94	7.70	1812.53
A-2	Core-1	Wrap-1	20.29±1.59	7.70	1812.53
A-3	Core-1	Wrap-1	26.19±0.75	7.70	1812.53
A-4	Core-1	Wrap-1	35.32±1.95	7.70	1812.53
A-5	Core-1	Wrap-1	42.19±1.39	7.70	1812.53
B-1	Core-2	Wrap-1	15.16±0.94	11.44	1344.78
B-2	Core-2	Wrap-1	20.29±1.59	11.44	1344.78
B-3	Core-2	Wrap-1	26.19±0.75	11.44	1344.78
B-4	Core-2	Wrap-1	35.32±1.95	11.44	1344.78
B-5	Core-2	Wrap-1	42.19±1.39	11.44	1344.78
C-1	Core-3	Wrap-1	15.16±0.94	17.24	1488.87
C-2	Core-3	Wrap-1	20.29±1.59	17.24	1488.87
C-3	Core-3	Wrap-1	26.19±0.75	17.24	1488.87
C-4	Core-3	Wrap-1	35.32±1.95	17.24	1488.87
C-5	Core-3	Wrap-1	42.19±1.39	17.24	1488.87
D-1	Core-1	Wrap-2	15.16±0.94	7.70	5500.37
D-2	Core-1	Wrap-2	20.29±1.59	7.70	5500.37
D-3	Core-1	Wrap-2	26.19±0.75	7.70	5500.37
D-4	Core-1	Wrap-2	35.32±1.95	7.70	5500.37
D-5	Core-1	Wrap-2	42.19±1.39	7.70	5500.37
E-1	Core-2	Wrap-2	15.16±0.94	11.44	4080.92
E-2	Core-2	Wrap-2	20.29±1.59	11.44	4080.92
E-3	Core-2	Wrap-2	26.19±0.75	11.44	4080.92
E-4	Core-2	Wrap-2	35.32±1.95	11.44	4080.92
E-5	Core-2	Wrap-2	42.19±1.39	11.44	4080.92
F-1	Core-3	Wrap-2	15.16±0.94	17.24	4518.16
F-2	Core-3	Wrap-2	20.29±1.59	17.24	4518.16
F-3	Core-3	Wrap-2	26.19±0.75	17.24	4518.16
F-4	Core-3	Wrap-2	35.32±1.95	17.24	4518.16
F-5	Core-3	Wrap-2	42.19±1.39	17.24	4518.16

the components have been listed in Table I. According to Table II, an experiment with factorial design including five, three and two levels of the initial helical angle of wrap component, diameter ratio of components and young modulus ratio of components has been conducted, respectively. Experiments were carried out under conditions of 22 °C and 65 RH% and to ensure the results, five repetitions for each combination have been considered until rupturing.

B. Production and Measurement

Fig. 1a shows the schematic structure of DC-HAY which is constructed by combining two same soft yarns with a higher diameter as core components and a stiff yarn with a lower diameter as wrap components that alternatively has been twisted around the core yarns. The samples were produced manually according to primary calculations based on the diameter of the component, pitch length and helical angle of the wrap component. Then, the actual helical angle of the wrap component was measured using

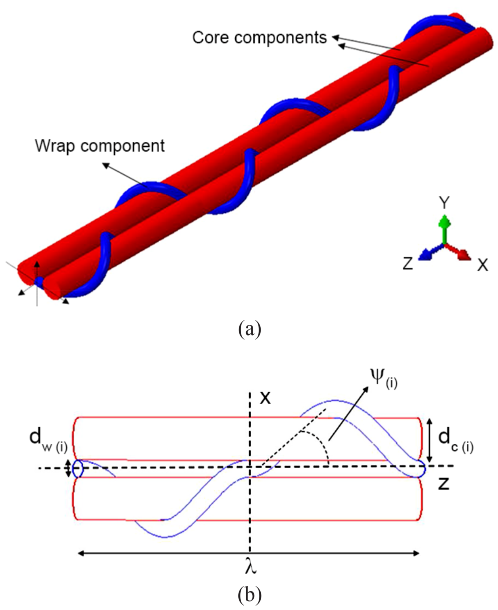


Fig. 1. Structure of DC-HAY at initial state: (a) schematic illustration and (b) geometrical parameters.

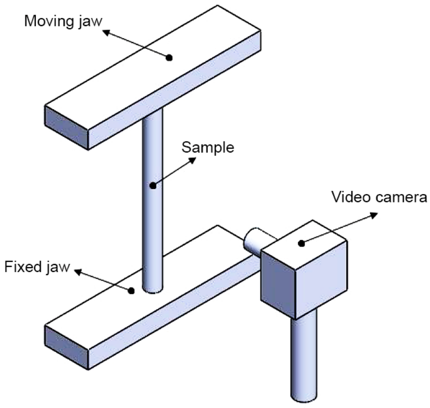


Fig. 2. Tools assembly of measuring the Poisson's ratio of helical auxetic yarn.

Digimizer software for further analysis.

The below Equations based on the geometry of structure at the initial state (Fig. 1b) have been used for production:

$$\psi_{(i)} = \tan^{-1}\left(2\pi\frac{\left(d_{c(i)} + d_{w(i)}\right)}{\lambda}\right) \quad (1)$$

$$TPM = \frac{1000}{\lambda} \quad (2)$$

Where, TPM, ψ, λ, d_c, and d_w are twist per meter, helical angle of wrap component in degree, pitch length in mm and diameter of the core and the wrap components (mm),

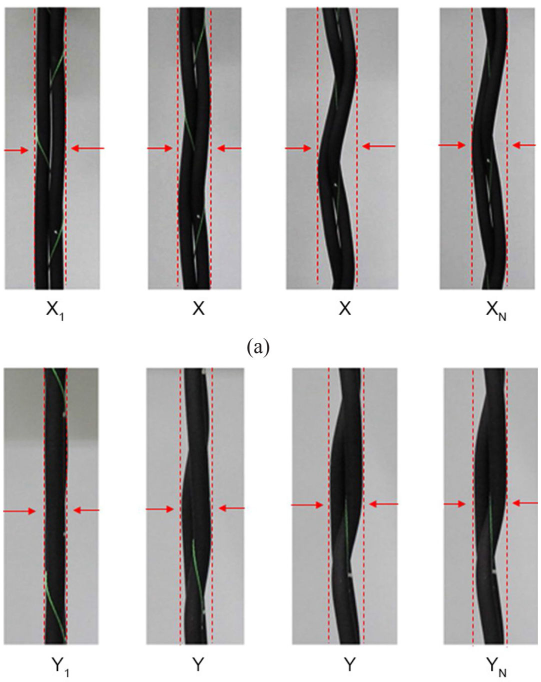


Fig. 3. Deformation of samples during the tensile loading through: (a) "X" direction and (b) "Y" direction.

respectively. The index i refers to the initial state of the structure. To measure the Poisson's ratio of DC-HAY, a tensile tester device (Instron 5566) according to ASTM D3822-01, with elongation speed as 200 mm/min and initial gauge length as 25 cm has been used. To trace the transversal strain of samples a video camera (Cannon PowerShot 530) has been utilized. Tools assembly has been shown in Fig. 2.

According to Fig. 1a, the deformation behavior of DC-HAY can be investigated through "ZX" and "ZY" planes. So, two Poisson's ratio for DC-HAY has been defined as the below equations:

$$\nu_{XZ(n)} = -\frac{\varepsilon_{X(n)}}{\varepsilon_{Z(n)}} \quad (3)$$

TABLE III
RESULTS OF POISSON'S RATIO MEASURMENT

Sample	Response	
	"X"	"Y"
A-1	-11.98±0.41	-11.50±0.31
A-2	-6.32±0.38	-5.97±0.33
A-3	-3.21±0.21	-2.98±0.11
A-4	-1.18±0.17	-1.03±0.11
A-5	-0.60±0.24	-0.53±0.12
B-1	-10.52±0.16	-10.05±0.05
B-2	-6.58±0.24	-6.14±0.18
B-3	-3.28±0.20	-3.05±0.19
B-4	-1.28±0.17	-1.13±0.09
B-5	-0.62±0.31	-0.57±0.13
C-1	-10.24±0.33	-9.93±0.41
C-2	-6.71±0.25	-6.30±0.45
C-3	-3.62±0.21	-3.30±0.11
C-4	-1.73±0.17	-1.33±0.08
C-5	-0.74±0.14	-0.60±0.19
D-1	-12.13±0.51	-11.63±0.24
D-2	-6.69±0.35	-6.12±0.39
D-3	-3.29±0.15	-2.99±0.12
D-4	-1.21±0.15	-1.11±0.40
D-5	-0.64±0.18	-0.58±0.22
E-1	-13.9±0.36	-13.14±0.45
E-2	-7.68±0.52	-7.02±0.20
E-3	-3.96±0.34	-3.41±0.22
E-4	-1.79±0.77	-1.59±0.08
E-5	-0.89±0.11	-0.80±0.19
F-1	-14.50±0.23	-14.17±0.47
F-2	-8.23±0.41	-8.16±0.44
F-3	-4.49±0.17	-4.26±0.19
F-4	-2.01±0.21	-1.87±0.12
F-5	-1.02±0.28	-0.92±0.15

TABLE IV
REASULTS OF ANOVA TEST

Main factors	Type	Levels	Code	Confidence level
Helical angle	Fixed	5	A	95 %
Diameter ratio	Fixed	3	D	
Modulus ratio	Fixed	2	E	

Source	D.F	S.S		M.S		F		P	
		"X"	"Y"	"X"	"Y"	"X"	"Y"	"X"	"Y"
A	4	2630.83	2499.83	657.71	624.96	10500.82	14430.66	0.00	0.00
D	2	11.19	11.32	5.60	5.66	89.35	130.68	0.00	0.00
A*D	8	2.14	3.40	0.267	0.43	4.26	9.80	0.00	0.00
E	1	37.29	29.41	37.29	29.41	595.37	679.11	0.00	0.00
A*E	4	32.13	29.94	8.03	6.74	128.25	155.51	0.00	0.00
D*E	2	11.20	15.86	5.60	6.74	89.43	183.05	0.00	0.00
A*D*E	8	14.12	15.36	1.77	1.92	28.19	44.32	0.00	0.00
Error	120	7.516	5.20	0.06	0.04				
Total	149	2746.43	2607.31						

$$\nu_{YZ(n)} = -\frac{\varepsilon_{Y(n)}}{\varepsilon_{Z(n)}} \tag{4}$$

Where, ε_X, ε_Y, and ε_Z are the strain at "X", "Y", and "Z" directions, respectively. The index (n) indicates the nth step of the calculation. In order to calculate the strain at "Z" direction, the following Equation has been used:

$$\varepsilon_{Z(n)} = \frac{TR(n-1)}{60L_0(N-1)}; \quad n \in [2.N] \tag{5}$$

Where, T is an effective time of the recorded video (s), R is the rate of elongation (mm/min), and L_0 is the initial gauge length (mm). In order to calculate the strain at "X" and "Y" directions, the lateral expansion of samples has been recorded by the video camera. Then, the video film has been divided into N images. In order to process the images, a program based on MATLAB software has been written. The image processing basic that used for the determination of lateral expansion through the "X" and "Y" directions are shown in Fig. 3.

Finally, Eqs. (6) and (7) have been used to determine the maximum NPR of DC-HAY through "ZX" and "ZY" planes, respectively.

$$\nu_{XZ(max)} = \min\left\{\nu_{XZ(2)}, \dots, \nu_{XZ(i)}, \dots, \nu_{XZ(n)}\right\} \tag{6}$$

TABLE V
RESULTS OF STUDENT-NEWMAN-KEULS TEST

A	Subset									
Level	1		2		3		4		5	
	"X"	"Y"	"X"	"Y"	"X"	"Y"	"X"	"Y"	"X"	"Y"
1	-12.20	-11.78								
2			-7.03	-6.66						
3					-3.68	-3.33				
4							-1.57	-1.32		
5									-0.73	-0.69
Sig.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

D	Subset					
Level	1		2		3	
	"X"	"Y"	"X"	"Y"	"X"	"Y"
1	-5.37	-5.12				
2			-5.06	-4.68		
3					-4.70	-4.46
Sig.	1.00	1.00	1.00	1.00	1.00	1.00

$$\nu_{YZ(max)} = \min\left\{\nu_{YZ(2)},\ldots,\nu_{YZ(i)},\ldots,\nu_{YZ(n)}\right\} \quad (7)$$

III. RESULTS AND DISCUSSION

Table III shows the interval estimation of average maximum NPR of samples at different directions of measurement at 95% confidence level. As can be seen in Table III, the means values of Poisson's ratio increase by reducing the initial helical angle of the wrap component, increasing the diameter ratio of components and increasing the modulus ratio of components. The highest maximum NPR among the samples belongs to the sample F1 for both directions of measurement. In order to analyze the variances, the ANOVA test has been performed using SPSS 23 software and then results for both directions of measurement have summarized in Table IV.

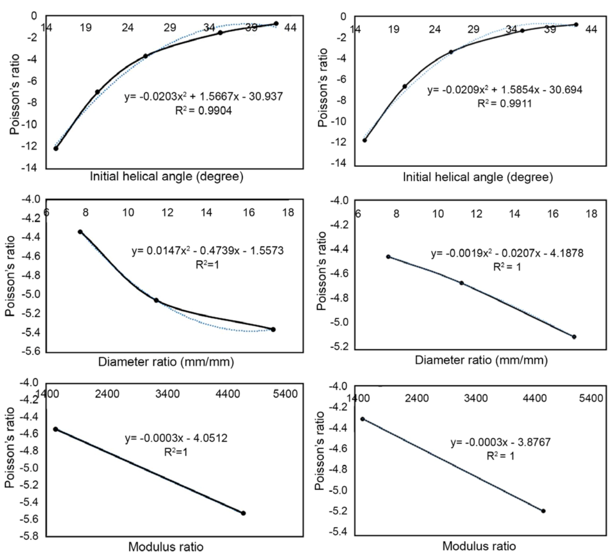
In order to define the subset of the level of the main factors, the Student-Newman-Keuls test has been utilized. According to Table IV, the D.F, S.S, and M.S refer to the degree of freedom, the adjusted sum of squares and adjusted means squares, respectively. The F value of variables has been calculated by dividing the M.S of the variable by M.S of error. The P-value of variables has been calculated based on the area under the appropriate null-sampling distribution of F which is higher than the observed F-statistic [21]. It should be pointed out that the below assumptions during the ANOVA test have been made:

- Normal distribution of population;
- Independent samples;
- Homogeneity of variances.

As can be seen through Table IV, the P-value ($P<0.05$) of all variables indicated that the effect of parameters on the given experimental layout is statistically significant. Based on the S.S value of main factors, the initial helical angle of wrap component and diameter ratio of components have the highest and lowest effect, respectively. Compared to similar previous studies in the case of helical auxetic yarn (HAY) [10-15], it can be found that some main parameters like helical angle, diameter ratio and modulus ratio of components are affecting also the auxetic behavior of DC-HAY. In addition, the effect of combined variables indicated that the main factors have different trends in different levels of each other.

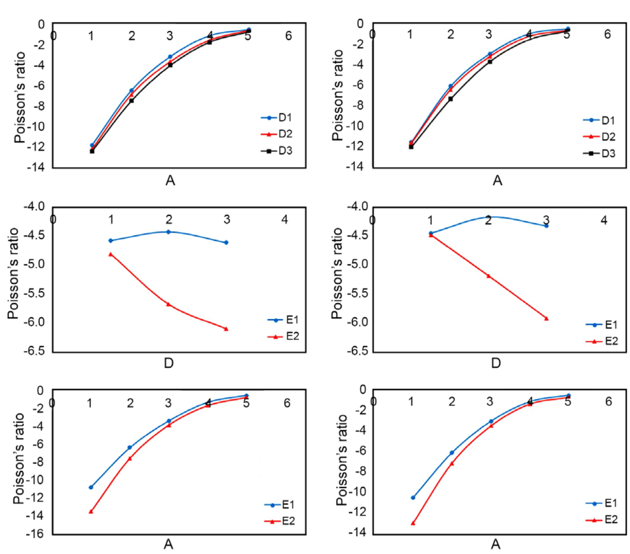
Based on the results of Table IV, there is a statistically significant difference between the modulus ratios of components. In addition, the total levels of this factor is two which does not require to be analyzed through the Student-Newman-Keuls test. The results of the analysis in the case of the initial helical angle of wrap component and diameter ratio of components have been summarized in Table V. It can be seen that there is a statistically significant difference between the selected levels of both factors that the subsets of them are equal to their selected levels. Further analysis has been used to investigate the trend of variation in the case of main factors at both directions of measurement as shown in Fig. 4.

According to Fig. 4 at both directions of measurement, increasing the initial helical angle of the wrap component will results in decreasing the maximum NPR of samples due to increasing the required strain to reach the maximum diameter of structure. Also, increasing the diameter ratio of components will results in a higher maximum NPR due



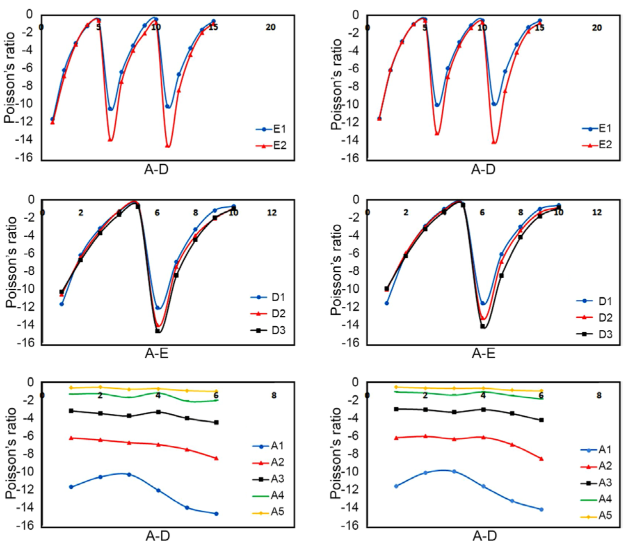
(a) (b)

Fig 4. Effects of main factors on Poisson's ratio of DC-HAY: (a) "X" direction and (b) "Y" direction.



(a) (b)

Fig. 5. Two-way interaction between the factors: (a) "X" direction and (b) "Y" direction.



(a) (b)

Fig. 6. Three-way interaction between the factors: (a) "X" direction and (b) "Y" direction.

to increasing the maximum diameter of the structure. The same results as the diameter ratio of the component could be found in the case of the modulus ratio of components. In fact, increasing the modulus ratio of components will increase the predominance of the wrap component over the core components that will result in a higher maximum NPR. Furthermore, the trends of variations indicated that there is a non-linear relationship between the initial helical angle of the wrap component and maximum NPR of structure. The same results could be found in the case of the diameter ratio of the component. There could be no absolute decision about the variation of modulus ratio of components trend due to selected two levels of the factor. When the effect of the interaction of main factors has been studied, the results of the analysis could be found as shown in Figs. 5 and 6. According to the results of Figs. 5 and 6, it could be said that there is interaction including 2-way and 3-way between the factors due to non-parallelism of plots which is in agreement with results of Table IV.

IV. CONCLUSION

In this work, the full factorial method was considered for the experimental design of samples. Some structural variables of samples, such as the initial helical angle of the wrap component, the diameter ratio of components, and the modulus ratio of the components, were considered as the main parameters. According to the statistical analysis, all the main parameters have a statistically significant effect on the Poisson's ratio of the samples. It was found that the initial helical angle of the wrap component has the highest effect on the maximum NPR of the structure at both directions. Also, the results of the ANOVA test showed that the 2-way and 3-way interactions between the factors exist. Finally, it can be deduced that to achieve a higher amount of maximum NPR, a lower amount of initial helical angle, higher diameter ratio of components, and higher modulus ratio of the components, must be considered during the manufacturing process of DC-HAY.

REFERENCES

[1] X. Ren, R. Das, P. Tran, T.D. Ngo, and Y.M. Xie, "Auxetic metamaterials and structures: a review", *Smart Mater. Struct.*, vol. 27, no. 2, 2018.

[2] Z. Wang and H. Hu, "Auxetic materials and their potential applications in textiles", *Text. Res. J.*, vol. 84, no. 15, pp. 1600-1611, 2014.

[3] P.B. Hook, K.E. Evans, and J.P. Hannington, "Moisture sensitive auxetic material", *Patent KR20060009826*, KR, 2006.

[4] T.C. Lim, "Semi-auxetic yarns", *Basic Solid State Phys.*, vol. 251, no. 2, pp. 273-280, 2013.

[5] Z. Ge, H. Hu, and S. Liu, "A novel plied yarn structure with negative Poisson's ratio", *J. Text. Inst.*, vol. 107, no. 5, pp. 578-588. 2015.

[6] N. Jiang and H. Hu, "Auxetic yarn made with circular braiding technology", *Basic Solid State Phys.*, vol. 256, no. 1, 2018.

[7] S. Liu, Z. Du, K. Xie, G. Liu, and S. Yang, "A novel interlaced-helical wrapping yarn with negative Poisson's ratio", *Fibers Polym.*, vol. 19, no. 11, pp. 2411-2417, 2018.

[8] Y. Shen and S. Adanur, "Mechanical analysis of the auxetic behavior of novel braided tubular structure by the finite element method", *Text. Res. J.*, vol. 89, no. 23-24, pp. 5187-5197, 2019.

[9] M. Razbin, A.A.A. Jeddi, M.J. Avanaki, and H. Dabiryan, "Double core helical auxetic yarn; novel structure for designing auxetic yarn", In *12th Iranian National Textile Engineering Conference (12th INTEC)*, 1102, 2020.

[10] Z. Du, M. Zhou, H. Liu, and L. He, "Study on negative Poisson's ratio of auxetic yarn under tension: part 1–theoretical analysis", *Text. Res. J.*, vol. 85, no. 5, pp. 487-498, 2015.

[11] Z. Du, M. Zhou, H. Liu, and L. He, "Study on negative Poisson's ratio of auxetic yarn under tension: part 2-experimental verification", *Text. Res. J.*, vol. 85, no. 7, pp. 768-774, 2014.

[12] A. Sibal and A. Rawal, "Design strategy for auxetic dual helix yarn systems", *Mater. Lett.*, vol. 161, no. 15, pp. 740-742, 2015.

[13] M. Kwietniewski and D. Miedzinska, "Numerical

analysis of helical auxetic yarn elastomeric core tension", In *AIP Conference Proceeding 2078*, 020044, 2019.

[14] S. Liu, Y. Gao, X. Chen, and Z. Du, "A theoretical study on the effect of structural parameter on tensile properties of helical auxetic yarns", *Fiber Polym.*, vol. 20, no. 8, pp. 1742-1748, 2019.

[15] M. Razbin, M.J. Avanaki, A.A.A. Jeddi, and H. Dabiryan, "A systematic study on the predictability of different methods to predict the maximum Poisson's ratio of helical auxetic yarn", *J. Text. Inst.*, 2020. doi: 10.1080/00405000.2020.1863568

[16] W.S. Ng and H. Hu, "Tensile and deformation behavior of auxetic plied yarns", *Basic Solid State Phys.*, vol. 254, no. 12, 2017.

[17] J. Zeng and H. Hu, "A theoretical analysis of deformation behavior of auxetic plied yarn structure", *Smart Mater. Struct.*, vol. 27, no. 7, 2018.

[18] J. Zeng, H. Cao, and H. Hu, "Finite element simulation of auxetic plied yarn structure", *Text. Res. J.*, vol. 89, no. 16, pp. 3394-3400, 2019.

[19] N. Jiang and H. Hu, "A study of tubular braider structure with negative Poisson's ratio behavior", *Text. Res. J.*, vol. 88, no. 24, pp. 2810-2824. 2018.

[20] N. Jiang, Y. Chen, and H. Hu, "Theoretical modeling on the deformation behavior of auxetic tubular braid made from modified circular braiding technique", *Basic Solid State Phys.*, vol. 257, no. 10, 2019.

[21] C.R. Hicks and K.V. Terner, Jr., *Fundamental Concepts in the Design of Experiments*, 5th Ed., Oxford University, 1999.

Part A: English Edition

Journal of Textiles and Polymers

Vol. 9, No. 3, 45-50, July 2021

http://dx.doi.org/10.48302/jtp.2021.136078

ORIGINAL PAPER

Metallocene and Ziegler-Natta Catalysts

Sandeep Vinod Vishwakarma and S.G. Kulkarni

Received: 18 March 2021, Accepted: 10 July 2021

Abstract- **Fifty years ago, Karl Ziegler and Natta won the Nobel Prize for their discovery of the catalytic polymerization of ethylene and propylene using titanium compounds with aluminum-alkyls as co-catalysts. Polyolefins are constantly growing and are now one of the most important high-consumption polymers. New metallocene/methylaluminoxane (MAO) catalysts have made it possible to synthesize polymers with highly defined microstructure, tacticity and steroregularity, such as long chain branched or block copolymers with excellent properties. Melt spinning of the fibers of metallocene-catalyzed isotactic polypropylene (PP) and standard equivalent of Ziegler-Natta isotactic polypropylene and therefore the properties of PP and several thermal and mechanical properties of fiber have been investigated. Ziegler-Natta catalysts were prepared by a reaction method which employed $Mg(OEt)_2$ as a precursor. Newly developed metallocene-catalyzed PP possesses higher isotacticity and crystallinity than commercial ones, so the mechanical properties of the final product are guaranteed.**

***Keywords*:** **Ziegler-Natta, metallocene, polypropylene, catalysts, polyolefins**

I. INTRODUCTION

Nonwoven fabric became a particularly important part of the textile industry. Compare to the global market average of 24%, the Indian market will occupy by 12% of the technical textiles manufactured by nonwoven technology. The nonwoven market is projected to grow from USD 40.50 billion in 2020 to USD 53.5 billion by 2025. For manufacturing of nonwoven fabric, there are different methods used to produce nonwoven fabrics supported by the web formation method, dry-laid nonwoven, spun-laid nonwoven, wet-laid nonwoven, supported web bonding, mechanical bonding, thermal bonding, and chemical bonding. The bonding types, the fiber type and therefore the manufacturing parameters determine the characteristic feature of the nonwoven. In contrast to standard engineering materials, these fabrics have better specific mechanical properties, strength to weight and stiffness to weight ratios [1]. The official definitions are provided by a professional organization like EDANA (European Disposables and Nonwoven Association) or INDA (International Nonwoven and Disposable Association). Melt-blown nonwoven and spun-laid nonwoven are most generally methods used for production of nonwoven fabrics. Melt-blown nonwovens are usually made through a continuous process. Fibers are spun then directly dispersed into a web by deflectors or are often directed with air streams. This method results in a faster belt speed and cheaper costs. Spun-laid nonwoven fabrics also called spun-bond nonwoven fabrics are produced by extruding molten polymer fibers through a spin net or die consisting of up to 40 holes per inch to create long thin fibers which are stretched and cooled by passing hot air over the fibers as they fall from the die. The approaching web is collected into rolls and subsequently converted to finished products. Spun-blown plays the role of imparting strength to nonwoven fabric and melt-blown is employed for barrier properties of nonwoven fabric. Differing types of polymers are utilized in the assembly of nonwoven fabrics like polyesters, polyetylene terephthalate (PET) and polypropylenes, and they are either within the type of small chips form or in the form of powder. Spun-bond/melt-blown/spun-bond, commonly

S.V. Vishwakarma and S.G. Kulkarni
DKTE Society's Textile and Engineering Institute, Ichalkaranji-416116, Kolhapur, India.

Correspondence should be addresses to S.V. Vishwakarma
e-mail: sandeeps342@gmail.com