Research on pressure of shoe upper knitted fabric on forefoot of the woman's instep

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Abstract - *The paper presents the method and results of the study on the relationship between elongation, tensile force of shoe upper knitted fabrics and their pressure on the forefoot of women's instep. The pressure of 5 shoe knitted fabrics on the instep of 10 young women in 4 postures (phase) is measured by the pressure measuring system using Flexscorce A301 sensor of Tekscan. The measured results are compared with the pressure value calculated according to Laplace's. The results of the study show that the pressure value of studied materials on the instep are directly proportional to their elongations and the four measuring postures; the regression equations between the elongation of 5 studied materials and their experimental pressure have a high correlation coefficient (R^2 = 0.9955); the regression equation between the material's tensile force and their pressure (to 100 mmHg) on the instep has a relatively high correlation coefficient (R^2 = 0.9538). This is an important basis for designing and selecting suitable knitted fabrics to make shoes with good pressure comfort, as well as shoes for diabetics.*

Keywords: Shoes Pressure, foot pressure, forefoot pressure.

1. INTRODUCTION

The pressure of the shoe uppers on the instep is one of the most important comfort criteria of the shoes. Excessive pressure of shoes on the feet affects their normal physiological processes and is one of the foot injury causes. In patients with foot complications such as gout, diabetes, etc., excessive pressure is also the cause of calluses, foot ulcers [1, 2]. In the world, 3% of diabetic patients have foot ulcers [1] and the most commonly affected forefoot of the instep [2].

Research [3] uses a sensor made by Walkinsense to determine the peak pressure value of three types of shoe upper on the instep. The results showed that the shape and width of shoe toe part affect the pressure value on the forefoot. Study [4] used Flexiforce sensor to determine the pressure at the forefoot of instep for 10 young men. The study shows that the pressure is affected by the area of contact between the instep and the shoe due to the difference in foot shape and phases of the foot steps. Research [5] suggests that the material's horizontal elongation arises due to changes in the foot girth or due to movement (or muscle contraction) or swelling. This increases the pressure of shoe upper on the foot instep. Research [6] used pressure sensors of Novel to compare the pressure on the instep of three types of sports shoes. The results showed a difference in pressure values on the foot instep of 3 shoe types.

One of the solutions to reduce pressure of the shoe uppers on the foot instep is the use of materials with good elasticity. And knitted fabric is the right choice. Knitted fabric is increasingly used to make shoes due to its soft, ventilation, good breathability and especially good elasticity. Currently, 3D knitted fabrics have replaced

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traditional materials which are glued from many layers (knit fabric + sponge, shoe upper lining) and change the technology of shoe production [7].

In this study, we determined the pressure of the uppers on the forefoot of the instep as the basis for selecting shoe materials and designing shoes, especially shoes for diabetics to ensure comfort, prevention of foot injury.

2. EXPERIMENTS

2.1. Subjects

In this study, 5 typical knitted fabrics (material systems) with basic characteristics as shown in table 1 were selected to study.

Table 1. Basic characteristics of shoe upper material systems

Symbol	Fabric type	Weight, g/m^2	Thickness, mm
M1	3D knitted fabric	325.0	2.13
M2	3D knitted fabric	350.0	1.13
M3	Knitted fabric + Foam + Tricot	295.0	2.66
M4	Mesh + Foam + Tricot	325.0	1.98
M5	Mesh 3D knitted fabric	305.0	1.92

Participants: 10 young women aged 21.8 ± 0.63 years, height: 155.9 ± 2.96 cm; weight: 47.5 ± 2.84 kg; ball girth circumference: 223.8 ± 1.2 mm and foot length: 230.0 ± 1.4 mm were selected.

2.2. Contents of research

Change of fabric elongation and pressure on the instep with the postures of gait cycle: Determining by the actual elongation of the material samples under the action of the foot and their experimental pressure follow the 4 postures (phase) of the gait cycle.

Correlation between elongation, tensile force of shoe material and pressure on instep: Determining the relationship between the material elongations and their average experimental pressure on instep of 10 objects. Test subjects stand in position 1 (stand up on 2 feet). The studied materials are stretched according to ASTM D4964-96 to no more than 30% to build the regression equation between their tensile forces and elongations. Using this equation to calculate the material tensile force on foot instep by their real elongation.

2.3. Method of research

2.3.1. Experimental method of determining the pressure on the foot

Pressure measuring system: Includes the shoe pressure device using Tekscan's A301 sensor located between the material layer and foot instep (Fig. 1 and 2) and the standing shelf [8].

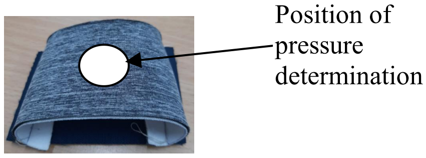

Fig. 1. Image of sample

Sample preparation: A sample of the material simulates the uppers of the instep (metatarsal) of the feet, the width of sample is 6 cm. The length (circumference) of the sample, keeping the dimension of the sole (6 cm) and the choice of 5 sizes for the material of the instep with an increment between sizes of 5 mm, namely: size 1: 13.7 cm, size 2: 13.2 cm, size 3: 12.7 cm, size 4: 12.2 cm, size 5: 11.7 cm. The sole of the foot (6 cm) uses a non-elastic woven fabric, making sure that the pattern only extends at the instep (Fig. 1). Using Juki DDL - 9000A-SS at Workshop of Hung Yen University of Education and Training to sew samples.

Measuring postures: 4 phases according to the foot step cycle (Figure 2, a-d) were selected.

Posture 1 (TT1): The legs are upright, the feet are in full contact with the ground (Fig. 2, a).

Posture 2 (TT2): The foot posture is tilted forward, the feet fully in contact with the ground (Fig. 2, b).

Posture 3 (TT3): The foot posture is straight, perpendicular to the ground, feet must be in full contact with the ground (Fig. 2, c).

Posture 4 (TT4): The foot posture is tilted backwards, the whole toe touches the ground (Fig. 2, d).

a b c d

Fig. 2. 4 postures of pressure determination: a. postures 1; b. postures 2; c. postures 3; d. postures 4

Process measurement: Firstly the measuring system is connected to the computer via the USB connection port, and then, start the software of the measuring system. The participant stands in the correct posture for about 30 seconds, observing on the display that the measurement results show a stable value, and then saving the measurement result. For each sample, 30 measurement values are taken and calculated the average as the final measurement result. Measure the girth of the foot when wearing sample to determine the actual elongation of the material.

2.3.2. Experimental method of determining the pressure on the foot by Laplace's formula

Determine the tensile force of the studied materials according to ASTM D4964-96 on the Mesdan Lab machine at the Textile and Leather Materials Testing Center of Ha noi University of Science and Technology. The working width of the specimen is 5 cm. The samples are stretched to an elongation less than 30%. From the experimental results, determine the regression equation between the material tensile force and their elongations. These equations are used to determine the tensile force of studied materials when are stretched on the instep.

Calculate the pressure of the shoe material on the foot instep according to their tensile force using the Laplace equation.

$$P = \frac{Fxnx4620}{GxW} \quad (1)\ [9]$$

Where: P is pressure, mmHg; F is tensile force, Kgf; G is perimeter, cm; n is layer of fabric; W is width of fabric, cm.

2.3.3. Data analysis

Use Excel 2013 software to process measurement results. The statistics were analyzed on Anova to verify the reliability of the measurement results.

3. RESULTS AND DISCUSSION

3.1. Change of fabric elongation and pressure on the forefoot with the postures of gait cycle

The ball girth of foot is increased from posture 1 (body weight is put on 2 legs) to posture 4 (body weight is put on forefoot of a bent foot). This stretches the shoe upper material (table 2).

Table 2. Elongation (f), %, of M1 in 4 postures (phase) of the gait cycle

Sample size	TT1	TT2		TT3		TT4	
	f1	f2	f2-f1,	f3	f3-f1,	f4	f4-f1,
1	2.12	2.72	0.60	4.08	1.96	4.80	2.68
2	6.90	7.63	0.73	9.13	2.23	9.88	2.98
3	11.67	12.34	0.67	13.99	2.32	14.78	3.11
4	16.86	17.62	0.76	19.26	2.40	20.08	3.22
5	21.88	22.65	0.77	24.36	2.48	25.21	3.33
Mean			0.71		2.28		3.06

Compared to the 1st post (TT1), in the 2nd position (TT2), the size of the feet increased, stretching the material sample 1 to 0.60 ÷ 0.77% (an average 0.71%), in the 3rd position (TT3) - an increase of 1.96 ÷ 2.48% (an average 2.28%), in the 4th position (TT4) - an increase of 2.68 to 3.33% (an average 3.06%) depending on sample sizes (table 2). Increasing elongation of studied materials increases their pressure on the forefoot (table 3 and Fig. 3).

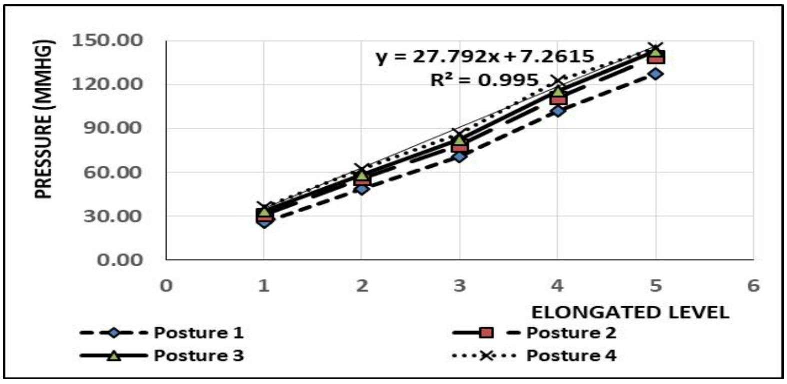

Fig 3. Correlation between elongation and pressure of sample 1 (M1) on forefoot in 4 postures

Table 3. Measured pressure, mmHg, of material samples on forefoot in posture 1 (TT1) and posture 4 (TT4)

Sample size	Sample 1			Sample 2			Sample 3			Sample 4			Sample 5		
	TT1	TT4	TT4/TT1	TT1	TT4	TT4/TT1	TT1	TT4	TT4/TT1	TT1	TT4	TT4/TT1	TT1	TT4	TT4/TT1
1	26.10	36.19	1.39	13.98	28.26	2.02	17.33	26.27	1.52	37.92	43.34	1.14	37.92	47.38	1.25
2	48.46	62.55	1.29	37.33	46.49	1.25	45.41	54.47	1.20	63.24	74.67	1.18	70.14	78.61	1.12
3	70.53	86.59	1.23	56.44	65.51	1.16	67.48	76.64	1.14	90.73	104.81	1.16	96.64	103.83	1.07
4	101.76	122.84	1.21	70.53	80.58	1.14	83.63	96.64	1.16	110.73	132.99	1.20	122.84	132.99	1.08
5	127.08	145.01	1.14	92.70	108.76	1.17	103.83	116.83	1.13	159.00	168.06	1.06	161.16	174.17	1.08
Mean			1.25			1.35			1.23			1.15			1.12

The data in table 3 shows that, comparing posture 1 to position 4 (the largest foot girth), the pressure of the knitted fabric samples on the forefoot area increases from 1.12 to 1.35 times. This shows that, even though knitted fabric has good elasticity, the pressure on the instep of the foot increases by an average of 1.22 times. Therefore, the use of shoes that do not fit the foot or shoes that are tight or the shoe upper is made of poor elastic materials, the pressure on the forefoot will increase sharply and cause foot injury.

3.2. Correlation between elongation, tensile force of shoe material and pressure on forefoot

The relationship between the material tensile forces and their elongations has high correlation coefficient (R^2=0.9763÷0.9988) (see Fig. 4 and Table 4).

Table 4. Regression between tensile and elongation of 5 material samples

Sample	Regression	R^2
M1	$y = 0.8368x + 2.2635$	0.9988
M2	$y = 0.3857x + 1.2937$	0.9763
M3	$y = 0.3876x + 2.8734$	0.9979
M4	$y = 0.0238x^2 + 0.8644x + 2.7298$	0.9975
M5	$y = 0.144x^2 + 1.062x + 1.3213$	0.9984

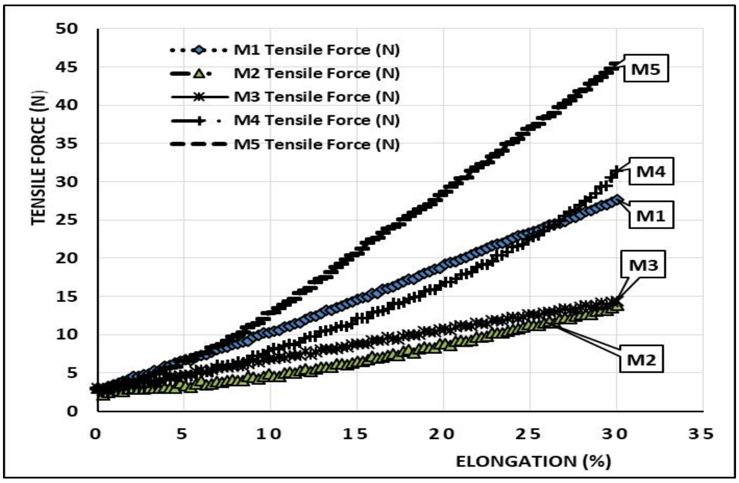

Fig. 4. Diagram of relationship between tensile force and elongation of 5 material samples

The result of determining the actual elongation and the pressure of the fabric samples on the instep of participants in position 1 is shown in table 5 and Fig. 5.

Table 5. Average elongation (f), mean of pressure (P), standard deviation (SD) and statistical significance level (p) of 5 material samples on the forefoot of 10 participants in posture 1

Sample	Sample size 1			Sample size 2			Sample size 3			Sample size 4			Sample size 5			p
	f, %	P, mmHg	SD, mmHg	f, %	P, mmHg	SD, mmHg	f,%	P, mmHg	SD, mmHg	f, %	P, mmHg	SD, mmHg	f, %	P, mmHg	SD, mmHg	
M1	2.12	26.10	1.22	6.90	48.46	1.86	11.67	70.53	2.50	16.86	101.76	3.66	21.88	127.08	4.35	0.009
M2	3.36	13.98	1.17	8.38	37.33	1.48	13.21	56.44	2.03	18.44	70.53	2.50	23.50	92.70	3.31	0.019
M3	2.70	17.33	1.18	7.63	45.41	1.77	12.43	67.48	2.36	17.62	83.63	2.98	22.65	103.83	3.79	0.010
M4	2.01	37.92	1.53	6.88	63.24	2.39	11.64	90.73	3.29	16.80	110.73	3.86	21.79	159.00	5.60	0.005
M5	1.93	37.92	1.53	6.80	70.14	2.62	11.56	96.64	3.35	16.72	122.84	4.35	21.71	161.16	5.87	0.003

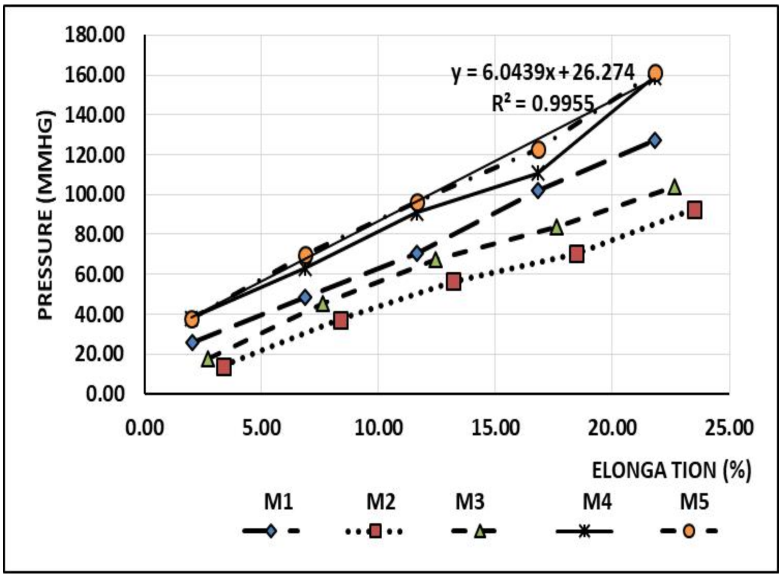

Fig. 5. Correlation between elongation and pressure of 5 material samples on the forefoot

The data in table 5 and Fig. 5 show that the pressure values and their increase according to the elongation of studied material samples are different (Fig. 5). For the same sample size (size 1), the pressure value of M2 was 13.98±1.17 mmHg (with a 3.36% elongation), while the pressure value of M4 was 37.92±1.53 mmHg (with an elongation of 2.01%). Therefore, on the same sample size, the material has a greater elongation, the pressure value is smaller and contrariwise. Using Anova to compare the difference of pressure value between 5 level of elongation (5 sample sizes) on the same material. The value $p < 0.05$ shows the difference in pressure value on the forefoot with level of material elongation. M2 has the smallest pressure value according to all 5 sample sizes. Its pressure of the sample size 5 reaches 92.7 mmHg. M5 gives the maximum pressure value of all 5 sample sizes. Its pressure at the sample size 3 reaches 96.64 mmHg. This is consistent with the stretching characteristics (with an elongation up to 30%) of the 5 fabric samples showed on Fig. 5.

From the regression equations between the tensile force and the elongation of 5 material samples (table 4), we calculate the tensile force (table 6) by their elongations on foot instep (table 2). Using Laplace's formula (1) to calculate their pressure on the foot instep (table 6).

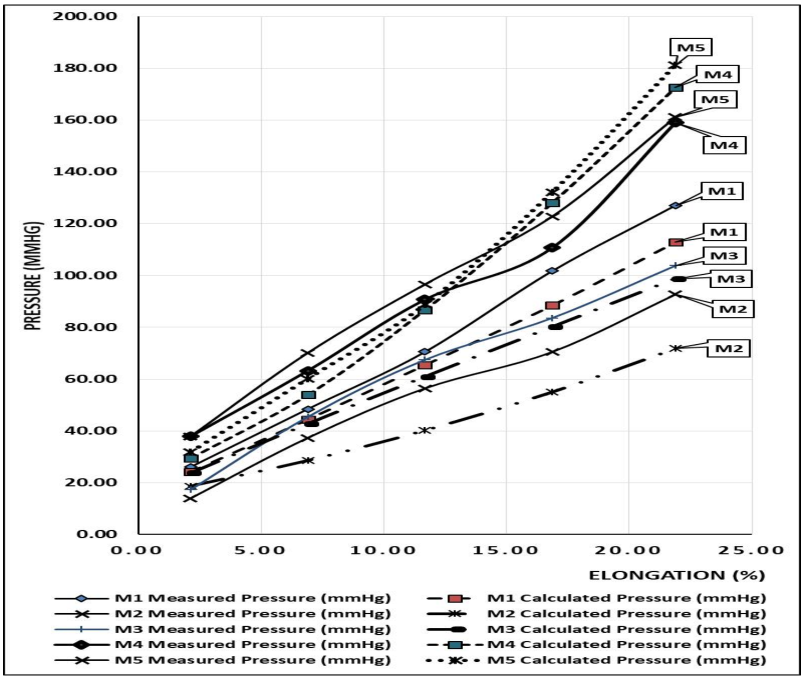

Fig 6. Comparing to measured pressure and calculated pressure of 5 material samples

Table 6. Measured pressure (Ptn, mmHg), calculated tensile force (Ftt, N/cm) and calculated pressure (Ptt, mmHg), of 5 sample in posture 1

Sample	Sample size 1			Sample size 2			Sample size 3			Sample size 4			Sample size 5		
	Ptn	Ftt	Ptt	Ptn	Ftt	Ptt	Ptn	Ftt	Ptt	Ptn	Ftt	Ptt	Ptn	Ftt	Ptt
M1	26.10	4.26	24.16	48.46	7.99	44.43	70.53	11.82	65.46	101.76	16.12	88.51	127.08	20.43	112.93
M2	13.98	3.37	18.69	37.33	5.21	28.58	56.44	7.37	40.22	70.53	10.13	55.03	92.70	13.22	71.84
M3	17.33	4.26	23.75	45.41	7.74	42.75	67.48	11.08	60.94	83.63	14.65	80.17	103.83	18.05	98.79
M4	37.92	5.23	29.41	63.24	9.65	53.89	90.73	15.65	86.64	110.73	23.24	128.06	159.00	31.32	172.56
M5	37.92	5.57	31.84	70.14	10.70	60.11	96.64	16.03	88.78	122.84	23.99	132.17	161.16	32.89	181.23

The data in table 6 and Fig. 6 show that the material samples have similar experimental and calculated pressures. At the 1, 2, 3 elongated level (sample sizes 1, 2, 3) (corresponding to the pressure value < 100 mmHg), the measured pressure and calculated pressure are almost equal. However, when increasing the extension to 5% (sample sizes 4), the theoretical pressure is quite far from the experimental pressure. Thus, for materials with low elasticity, the calculation formula is applied only with an extension of less than 15%.

In the study [10], we determined that the comfort pressure range of shoe upper material on the instep of women's foot is from 69.60 mmHg to 80.39 mmHg. The limit of allowed pressure value is 70 mmHg. Therefore, in this study we are interested in pressure values below 100 mmHg of the study material samples on the foot instep.

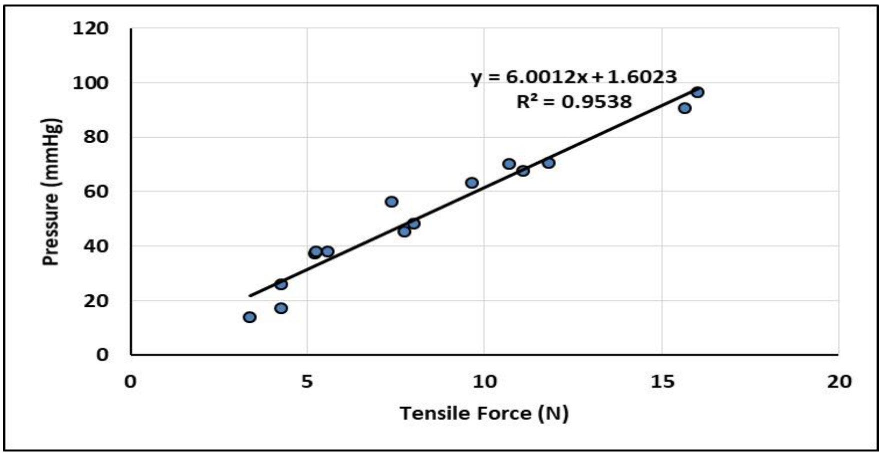

Fig 7. Correlation between tensile force of material samples and their experimental pressure (below 100 mmHg) on foot instep in posture 1

The regression equation in Fig. 7 shows that the material's tensile strength (x, N/cm) and pressure (y, mmHg) are directly proportional and closely related ($R^2 = 0.9538$). According to this equation, from a maximum pressure of 70 mmHg on the forefoot, the maximum tensile force of the sample is determined to be 11.4 N. Thus, to select a knitted fabric for making shoe upper, the fabric sample with 5 cm of width needs to be stretched according to ASTM D4964-96 by maximum tensile force of 57 N and recording its elongation. In order to make shoes for people who do not have foot problems, we recommend a minimum of 5% material elongation. Because, as stated in section 3.1, during the use of shoes, due to the change in load on the foot and its bend, its ball girth increases by 3.5%. In addition, the ball girth of foot increases to 5 mm or 2.5% when foot subjected to long-term body load (from morning to afternoon). In order to make shoes for patients with foot complications such as diabetes, gout patients, the shoe upper material should have a minimum of 10% elongation, because the ball girth of patient's feet are increased significantly due to edema or swelling. With horizontal extension is 10 percent (equivalent to the absolute elongation of the shoe upper above 14 mm), the shoe ensures pressure comfort and minimizes foot injury. Specially, feet are the same length but there are a difference in their ball girth within one size of foot girth (6 ÷ 8 mm) that can use the same size of shoes.

4. CONCLUSION

The pressure of the knitted fabrics on the forefoot of the instep are proportional to their elongations and tensile force. There is the regression equation between the tensile force (x, N/cm) of the materials and their pressure below 100 mmHg (y, mmHg): $y = 6.0012x + 1.6023$ with $R^2 = 0.9538$.

In the process of using shoes, feet move (standing and going) and change in dimension due to long-term body load, due to a change in load on the foot and its bending or due to edema or swelling in patients with foot complications. That stretches the shoe uppers. For the studied shoe upper materials, due to changes in foot load and foot bending, the average material elongation is 3.42%, which increases the pressure of the shoe material on the forefoot 1.22 times. So it is appropriate to use materials with good elastic elongation such as knitted fabrics (M1, M2 and M3) to make comfort shoes. The research results are an important basis for selecting materials for shoe uppers to ensure pressure comfort and prevent injury to the user's feet, especially shoes for patients with foot complications such as diabetes.

ACKNOWLEDGEMENT

Authors of this study would like to thank Hung Yen University of Education and Technology; Ha Noi University of Science and Technology has assisted us in the experimental process to complete this study.

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