Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Design and Heat Setting of 3D-Weft Jacquard Knitted Effect on some properties related to Thermal Insulation

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Abstract

The knitting industry contributes very much to the progress of the textile industries because of its diversity in production, its affordable cost, and its ease of operation, in addition to its popularity among consumers thanks to its advantages; the most important are comfort, elasticity, aesthetic appearance, and thermal insulation. The composition of the three-dimensional weft jacquard knitted fabrics affects the thermal insulation property and achieves thermal balance for the body, thus providing thermal comfort. This research aims at finding consistent standards that clarify the effect of the firmness of the three-dimensional double-weft knitted fabrics used in women's outerwear on the thermal insulation property.

In this research, five designs with a double structural composition were produced, differing in double areas and firmness areas. The produced samples were treated by heat treatment, and some of the performance properties of the produced samples were measured. The research reached these results: There is a direct relationship between the double design area, the firmness area, and the thermal insulation property, so a direct relationship between the heat treatment time and the thermal insulation property, and a direct relationship between the thickness and the thermal insulation property of the three-dimensional double weft jacquard fabrics.

"Keywords: Jacquard Fabrics; Three-dimensional Knitted Fabrics; firmness area; Thermal Insulation; 3D; Air gaps; Properties."

1. Introduction

The knitting industry is the second most widespread industry after the textile industry. It contributes greatly to the progress of the textile industry at the present time because of the diversity, affordable cost, and ease of operation [1], [2], [3], [4]. In addition to the increasing consumer demand for its use in all types of clothing for men, women, and children alike, thanks to its many advantages [1], [2]. The most important of these features are the characteristics of comfort, elasticity, thermal insulation, diverse aesthetic appearance, and ease of repair [5], [6].

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Received date 2023-04-02; revised date 2023-05-16; accepted date 2023-05-22
DOI: 10.21608/EJCHEM.2023.203586.7809

Three-dimensional fabrics are defined as fabrics whose threads are arranged by turns in three orthogonal directions to produce a compact three-dimensional woven structure [7]. That is, they are fabrics with a third dimension in thickness, where the threads intertwine longitudinally in the direction of X, transversely in the direction of Y, and vertically in the direction of Z, which is responsible for creating strength and stiffness, as well as thickness in the fabric structure [8].

Three-dimensional weft knitting fabrics are a new field of development of double-knitted fabrics, which can be produced as a knitting fabric with two separate layers of fabric, provided that they are connected to each other by means of a number of separate, spaced threads that connect the two layers perpendicularly at an angle of 90°. It is easy to separate them into two layers according to final uses [9].

One of the most important characteristics of three-dimensional weft knitting is its suitability for winter uses since it provides the body with a higher specific heat resulting from a coarse linear density of the threads and an increase in the length of the formed fabric loops, which results in a greater thickness of the woven fabric. This leads to an increase in the thermal insulation of the three-dimensional fabric [10]. The thermal insulation feature of knitted fabrics provides that balance between body heat and the external environment. Therefore, it offers thermal comfort and protection from external temperature fluctuations [11].

Double-knitted fabrics are defined as having a structural composition of two layers of fabric, each overlapping with the other at points of firmness to give the product the characteristic of stability, thus facilitating the cutting and sewing process [12]. Double-knitted fabrics are distinguished from single-layer fabrics by providing many aesthetic properties for design, and the possibility of using them on both sides [13]. Likewise, the increase in thermal insulation in double-knitted fabrics increases the linear density, the length of the fabric loops, and the thickness of the fabric [14].

Firmness in double-knitted fabrics is defined as the adhesion of two fabrics together to become one fabric that cannot be separated after production. The two sides of the cloth are held together by the fabric loops of the platinum or under the overlapping edges that are inside the cloth Sometimes, the two sides are produced together and are far enough to contact the fabric loops of the platinum and are cut from the inside to produce two separate cloths of one side [10].

Jacquard knitwear production includes the introduction of special devices for selecting needles, depending on the design used. Therefore, the use of a mixture of colors with devices for selecting needles enriches the jacquard design [15]. The data management system in the electronic jacquard is through equipping the knitting machine with the electronic jacquard with one of the elements as a specialized computer, an erasable memory that can be erased and reprogrammed, a floppy disk or a compact disk, and a flash memory [16].

Among the advantages of the jacquard composition are the multiplicity of produced designs, the less likely dismantle compared to non-jacquard knit compositions, and the connection between the front and back loops of the fabric prevents the fabric from disintegrating and weakening when subjected to various stresses [17].

Since the stitch is the basic structural unit for all knitting compositions, it is considered the basic criterion for the structural composition of jacquard fabrics, and then the jacquard is produced based on those basic stitches by making a group of needles in the non-operating position and therefore it cannot be fed with new threads. The old fabric loops are not replaced; accordingly, the missing loops' positions withdraw the threads in the form of floats. Thus, the structural elements of all jacquard fabrics consist of loops and floats; and knitted jacquard includes ribbed fabrics and double jersey, where the fabric appears in a different and unconventional color and texture [18].

Textile and clothing consumers have become increasingly aware of the importance of comfort along with aesthetic appearance. Thus, comfort has become one of the main characteristics of clothing that influence product selection. Clothing comfort includes three main considerations: thermal, physiological, sensory, and psychological [19], [20].

Human thermal comfort depends on an integrated combination of clothing, climate, and physical activity. Accordingly, thermal comfort necessitates maintaining the basic human temperature within limits close to 37 Celsius degrees during all types of its various activities [21].

The thermal comfort of textiles means providing thermal balance for the body through the ability of fabrics to maintain body temperature through the transfer of heat and perspiration and the creation of a microclimate for it next to human skin that maintains temperature and humidity for it, thus achieving normal physical activity and a good health condition. Thermal comfort is affected by the type of fiber, the properties of the thread, the type of woven fabric, and its final processing [22].

Textile fibers by themselves do not have a great capacity for thermal insulation, and the amount of thermal insulation in woven or knitted fabrics, to a large extent, is because of the air trapped during the structure of the knitted fabrics or textile fabrics. Although there are clear differences between the thermal insulation capacity of the different textile fibers, these differences lose their effectiveness due to the effect of the air present through the fabric [1].

It is noted that usually the degree of warmth or coldness of any type of fabric is judged as a result of the feeling of touch that occurs between the fabric and the body, but this feeling should not be mixed with the ability of the fibers to insulate thermally. As the feeling of warmth by touch depends on the area of adhesion between the cloth and the body; the greater this area, the greater the ability of the cloth to cool the body, and the less the area of adhesion, the greater the ability of the cloth to keep warm [21].

2. Experimental Work

2.1. Specifications of The Studied Fabric Samples

The double structure composition was used, the material used is acrylic (28/2), (acrylic lycra axial thread 28/2, the percentage of lycra is 4%)

The machine used in the production of samples is a bed rectangular weft knitting machine, gauge (7).

The structural compositions used for fabrics are (double) structures.

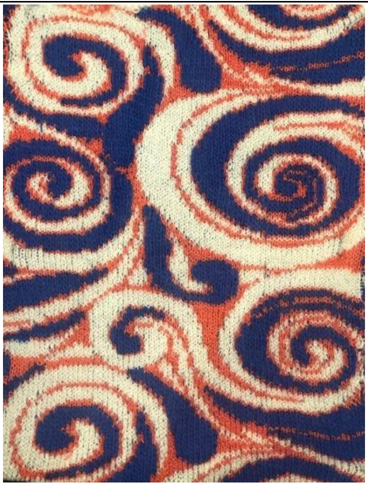
15 different samples in double areas, all of them are shown in Table (1), and Table (2) as flowing:

Table 1. Specifications of The Studied Samples and The Practical Experiments

Sample Number	Design Number	Treatment time in seconds
1	1	Without Treating
2		7
3		14
4	2	Without Treating
5		7
6		14
7	3	Without Treating
8		7
9		14
10	4	Without Treating
11		7
12		14
13	5	Without Treating
14		7
15		14

The studied samples were prepared with heat treatment for a period of 7 seconds and 14 seconds. The following is an illustration of the designs produced without the heat treatment, and also after being subjected to the heat treatment.

Table 2. Figures of The Studied Samples before and after heat preparation

Design Number	Without preparation	Prepared for 7 seconds	Prepared for 14 seconds
1			
2			

3			
4			
5			

2.2. Laboratory Tests Performed on Produced Samples

Some of the performance properties of the produced samples were measured, which are the number of rows and columns in the unit of measurement, thickness, weight per square meter, air permeability, and thermal insulation, by conducting tests in the testing laboratory at the Faculty of Applied Arts, Damietta University, which are:

- Fabrics weight in gm/m^2 : This test was carried out according to, ASTM-3776 [23].
- Thermal Transmittance of Textile Fabrics (Tog): This test was carried out according to

ISO 11092 [24].

- The number of Wales and Courses per unit area is determined using suitable magnifying and counting devices. This test was carried out according to ASTM, D3887.
- Thickness measurement (mm): This test was carried out according to ASTM D1777 – 96[25].
- Air permeability (cm3/cm2/sec): This test was carried out according to ASTM D737 [26].

3. Result and discussion

3.1 Samples characterizations

Tests were applied on the produced 3D jacquard weft knitted fabrics with different designs. The results were as follows in Table 3.:

Table 3. Experiments Results

Sample Number	Design Number	Firmness Area	Double Area	Processing time Second	number of columns/ inch	number of rows/ inch	weight gm/m^2	Thick-ness mm	air permeability cm3 / cm2 / second	Thermal Insulation Tog
1	1	%40	%60	Without	10,7	12.6	498.33	3	59.2	86.55
2				7	13.21	13.96	642.26	3.98	48	90.55
3				14	15.92	16	812.23	4.56	47	101.22
4	2	%36	%64	Without	10.9	12.56	488.87	3.11	57.44	98.77
5				7	13.46	14.16	611.45	3.56	49	100
6				14	15.16	15.98	804.89	4.86	47.6	104.55
7	3	%33	%67	Without	10.9	12.86	467.77	3.22	42.77	146.88
8				7	14	13.96	599.66	4.46	40.51	150.36
9				14	15.98	16.11	780.97	5.42	39.77	160
10	4	%30	%70	Without	10.6	11.99	482.25	3.12	45.1	149
11				7	13.72	13.88	494.13	4	44.22	154.66
12				14	15.27	15.46	780.36	5.98	42.88	165
13	5	%25	%75	Without	10.8	12.46	490.55	3.11	41.76	151.55
14				7	13.11	14.22	500.33	4.12	40	158.66
15				14	15.76	16.62	787.36	5.88	39.89	168.4

After conducting practical experiments, the results were counted. ANOVA test, correlation coefficient, and quality coefficient were made to verify the research hypotheses.

3.2 Significant/insignificant effect

Due to illuminate the effectiveness of different variables in producing samples ANOVA test with a p-value (0.05) has arisen as shown in Table 4. The results indicated that the difference in the double area percentage in the design (60%, 64%, 67%, 70%, and 75%) affect significantly on the air permeability and thermal insulation of the produced three-dimension samples, also Firmness area % in the design (40%, 36%, 33%, 30%, and 25%) affect significantly on the air permeability and thermal insulation of the produced three-dimension samples. Moreover, the results stated that the variation of the heat setting time had influential effectiveness on the Courses density, weight, thickness, air permeability, and thermal insulation of the produced three-dimension samples.

Table 4. ANOVA Results of The Produced Three-Dimension Samples

Characteristic	**P-value**		
	Different Design		Heat setting time
	Double area % in the design	Firmness area % in the design	
Wales density (wale/Inch)	0.484	0.594	0.164
Courses density (Course/Inch)	0.066	0.870	0.000001*
Weight (gm/m^2)	0.238	0.818	0.000001*
Thickness	0.194	0.850	0.000001*

(mm)			
Air permeability (cm3/cm2/ sec.)	0.002*	0.020*	0.021*
Thermal Insulation (Tog)	0.000001*	0.000001*	0.000001*

* Significant effect

3.3. The effect of double space area and heat treatment on thermal insulation

The effect of double space area on thermal insulation was illustrated as follows:

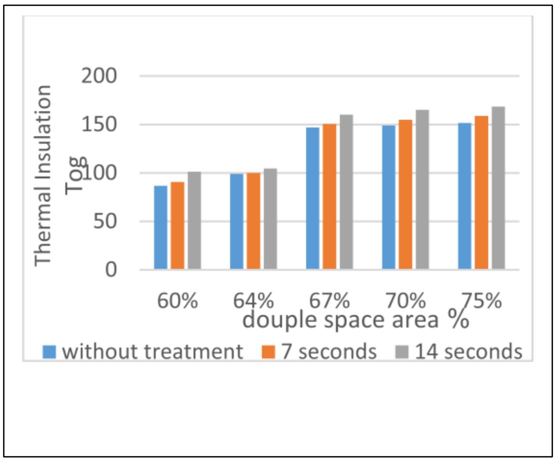


Fig. 1. The Effect of the Design (Double Area) on Thermal Insulation.

Fig. 1 shows the effect of the design (double area) on thermal insulation. It was found that sample No. (15) with a double area of 75% is the highest sample for thermal insulation with a thermal treatment of 14 seconds; and the lowest sample No. (1) with a double area of 60% and this is due to the air pockets that increase the double area. In other words, there is a direct relationship between the double area and thermal insulation.

The effect of Heat treatment Time on Thermal Insulation was illustrated as follows:

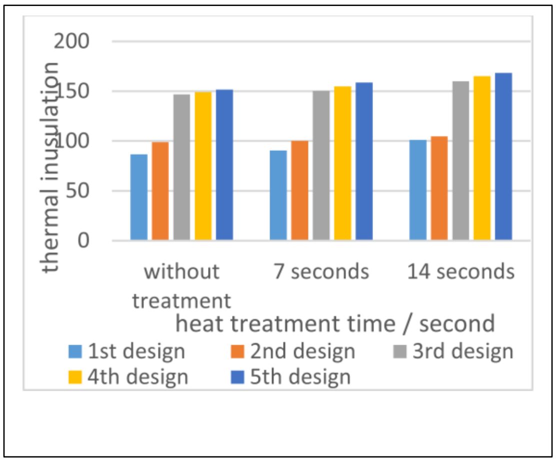


Fig. 2 The effect of Heat Treatment Time on Thermal Insulation.

Fig. 2 shows the effect of heat treatment time on thermal insulation. The samples treated for 14 seconds are better than those without treatment; meaning there is a direct relationship between the treatment time and thermal insulation. This is a result of a shrinkage in the number of rows and columns, which led to a decrease in the distances between the stitches, which in turn led to a decrease in the heat loss of the fabrics. This result is consistent with the results of the study [27] Despite the different types of produced fabrics and theirs construction

3.4. Correlations between properties of the produced 3D weft knitted fabrics and the Thermal insulation

Correlations between properties of the produced 3D weft knitted fabrics and the thermal insulation were evaluated by calculating R2 and find the linear equation follow

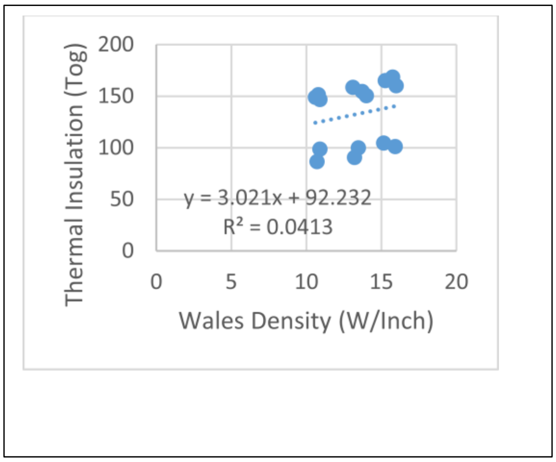


Fig. 3. Correlation between Wales density and Thermal Insulation

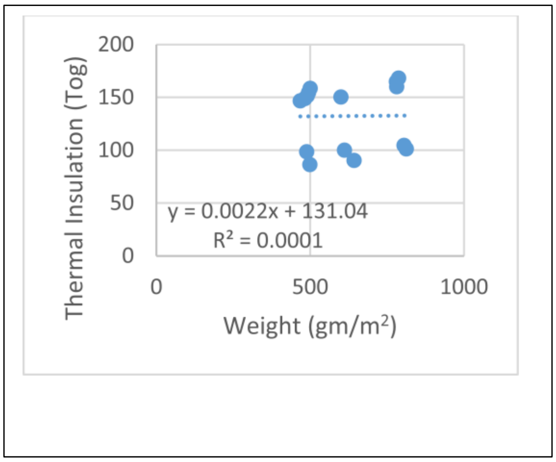


Fig. 5. Correlation between Weight and Thermal Insulation

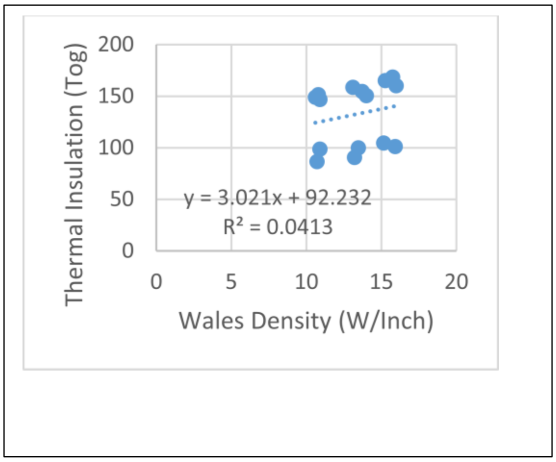


Fig. 4. Correlation between Courses density and Thermal Insulation

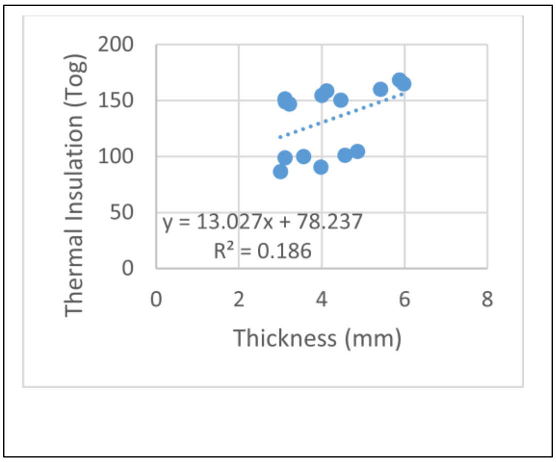


Fig. 6. Correlation between Thickness and Thermal Insulation

Fig. 3 and Fig. 4 show the Correlation between wales and courses densities per inch and thermal insulation. The value of the Correlation coefficient (R=0.203 for wales density, R=0.175 for courses density) indicate that there is a low positive relationship between Stitch density and thermal insulation. By increasing the heat setting time, the number of rows and columns increases. Thus, heat setting the cloth for 14 seconds is better than setting it for 7 seconds; this increase affects the thickness of the cloth, and - in turn - affects the thermal insulation.

Fig. 5 and Fig. 6 illustrate the Correlation between weight, thickness, and thermal insulation. The value of the Correlation coefficient (R=0.1 for weight, R=0. 44 for thickness) indicates that there is a low positive relationship between weight and thermal insulation but there is a strong positive relationship between thickness and thermal insulation. With the increase in heat setting, shrinkage of fabrics occurs in both directions of columns and rows, and thus the thickness and weight increase, which – in turn - increases the thermal insulation. In other words, there is a direct relationship between thickness, weight, and thermal insulation.

This result is consistent with the results of the study [1]. Despite the different types of fabric design, different ratios of firmness area, and the gauge

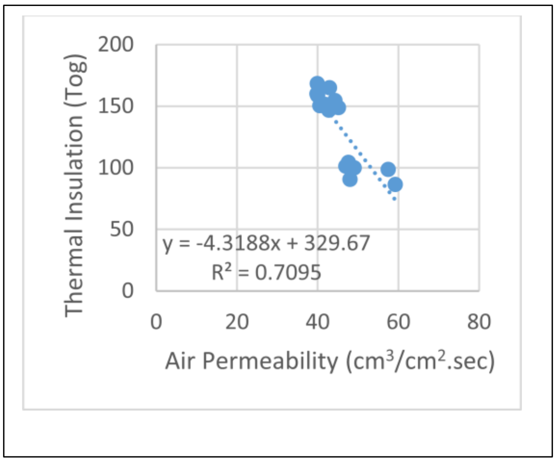


Fig. 7. Correlation between Air Permeability and Thermal Insulation

Fig. 7 illustrates the Correlation between air permeability and thermal insulation and explains the inverse relationship. The value of the Correlation coefficient (R=0.842) indicates that there is a strong negative relationship between air permeability and thermal insulation. That means the higher the air permeability, the lower the thermal insulation - with the increase in heat setting, the number of columns and rows increases, and the thickness increases accordingly, so the air permeability decreases and the thermal insulation increases.

Similar results have been found by other researchers [21],[27]. So, that fact means that the fabric has air between its structure and maintains the thermal Insulation rate.

3.5. Ranking Samples by calculating relative values of physical and mechanical properties of samples

Preparation of relative values of physical and mechanical properties of fabric samples was done by researchers as follows:

Table 5. The Relative Values of the Physical and Mechanical Properties of the Studied Fabric Samples

Sample No.	Design No.	Firmness Area (%)	Double Area (%)	Heat Setting Time (Sec.)	Courses/Inch	Wales/Inch	Weight	Thickness	Air permeability	Thermal Insulation	Quality coefficient(%)	Ranking of quality coefficient
1	1	%40	%60	0	66.96	75.81	61.35	50.17	100.0	51.4	67.615	15
2				7	82.67	84	79.07	66.56	81.08	58.65	75.33833	9
3				14	99.62	96.27	100	76.25	79.39	60.11	85.27333	5
4	2	%36	%64	0	68.21	75.57	60.19	52.01	97.03	59.38	68.73167	12
5				7	84.23	85.2	75.28	59.53	82.77	53.77	73.46333	10
6				14	94.87	96.15	99.1	81.27	80.41	62.08	85.64667	4
7	3	%33	%67	0	68.21	77.38	57.59	53.85	76.18	88.68	70.315	11
8				7	87.61	84	73.83	74.58	74.70	89.29	80.66833	6
9				14	100	96.93	96.15	90.64	72.43	98.1	92.375	2
10	4	%30	%70	0	66.33	72.14	60.4	52.17	70.54	87.22	68.13333	14
11				7	85.86	83.51	61.6	66.89	67.57	91.84	76.21167	8
12				14	95.56	93.02	96.94	100	67.38	95.01	91.31833	3
13	5	%25	%75	0	67.58	74.97	53.8	52.01	72.25	89.99	68.43333	13
14				7	82.04	85.56	61.86	68.9	68.43	94.22	76.835	7
15				14	98.62	100	97.81	98.33	67.18	100	93.65667	1

Table 5 shows the relative values of the physical and mechanical properties and the quality coefficient of the studied fabric samples. Below are the diagrams that show the relationships between the different properties of the fabrics.

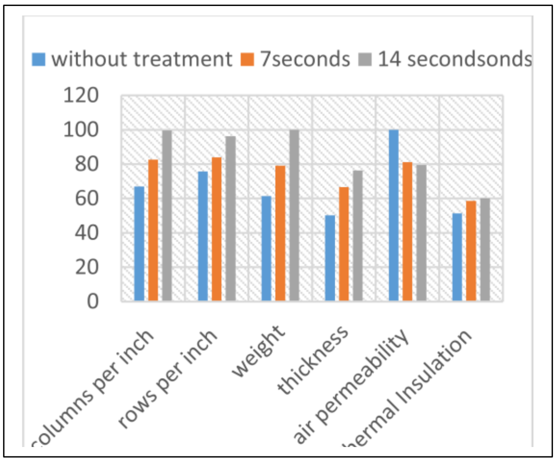


Fig. 8. The Relative Values of the Physical and Mechanical Properties- Double Area 60%

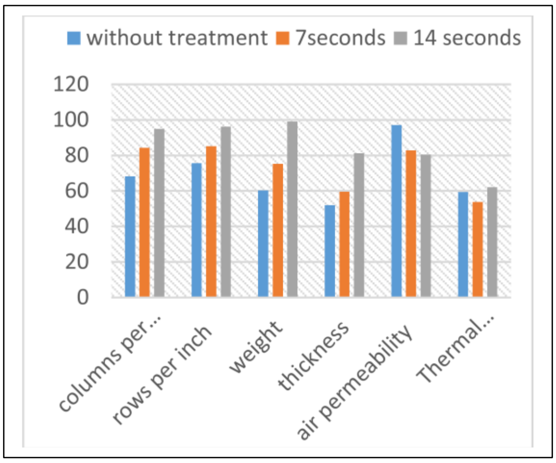


Fig. 9. The Relative Values of the Physical and Mechanical Properties- Double Area 64%

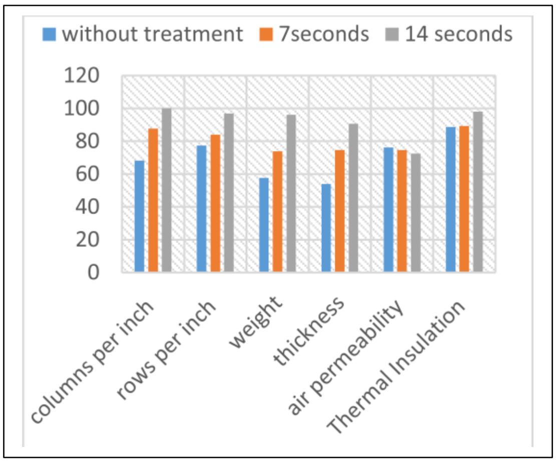


Fig. 10. The Relative Values of the Physical and Mechanical Properties- Double Area 67%

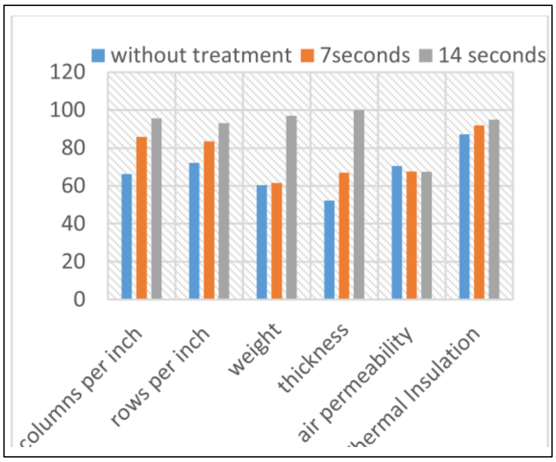


Fig. 11. The Relative Values of the Physical and Mechanical Properties- Double Area 70%

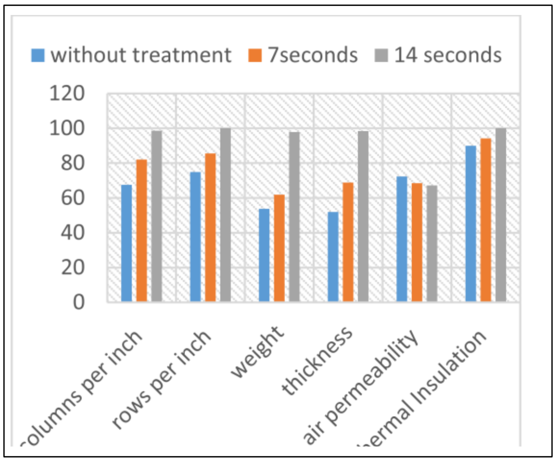


Fig. 12. The Relative Values of the Physical and Mechanical Properties- Double Area 75%

Table 5 and Figures from **Fig. 8** to **Fig. 12** show the relative values of the physical and mechanical properties, without heat setting, when the studied fabric samples are settled by heat for 7 seconds, and for 14 seconds; as well as the quality coefficient. Thus, the order of the samples was as follows:

Sample No. (15) with a rate of 93.65%, followed by Sample No. (9) with a rate of 92.37%, followed by Sample No. (12) with a rate of 91.32%, followed by Sample No. (6) with a rate of 85.64%, and finally Sample No. (3) with a rate of 85.27%

4. Conclusions

Through the previous presentation of the research results, the research hypotheses are verified as follows:

- There is a relationship between the design double area, the firmness area, and the thermal insulation of the three-dimensional double-weft jacquard fabrics.
- There is a relationship between the heat setting time and the thermal insulation of the three-dimensional weft knitted fabrics.
- There is a relationship between the thickness and thermal insulation of the three-dimensional double-weft jacquard fabrics.
- From all previous correlations it can be concluded that the higher relation affects thermal insulation in 3D weft knitted jacquard fabrics is between air permeability (R=0.842) followed by thickness (R=0.44) then stitch density (R=0.203 for wales density, R=0.175 for courses density) and finally weight (R=0.1).

5. Conflicts of interest

"There are no conflicts to declare".

6. Formatting of funding sources

This research has no funding from any sources. It is self-funded from the researchers.

7. Acknowledgments

The researchers would like to acknowledge prof dr. Fayrouz; professor of spinning, weaving, and knitting, Faculty of Applied Arts, Damietta University for providing help during the research and the laboratory of the Faculty of Applied Arts, Damietta University for samples testing.

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