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Design and Development of an Innovative Test Device Capable of Automatically Performing Carpet Static Loading Tests

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ABSTRACT

The resistance of carpets to texture deformation is considered one of the most important properties that affects the quality of carpet. Static load is an essential factor that has a profound impact on carpets causing compression of carpet pile yarns. Mainly, two tests are available to test the performance of carpets in terms of compressibility and resilience, including thickness loss after brief moderate static loading and thickness loss after prolonged heavy static loading. Currently, the commercially available test devices have drawbacks, including a requirement for an additional apparatus to test performance, conducting tests manually which leads to personal faults, and inability of storing test data. In this study, a newly developed test device for measuring compressibility and resilience performance of carpet was designed and manufactured. The newly designed test device is statistically verified and capable of performing carpet thickness measurement, brief moderate static loading and prolonged heavy static loading tests automatically.

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KEYWORDS

Carpet, Resilience, Static loading, Machine design

1. INTRODUCTION

Indeed, carpets are frequently utilized by human in different aspects of life. Carpets are used in order to obtain sound and heat insulation, in addition to provide an aesthetic appearance that is favourable by end-users. [1]. During usage, carpets are prone to many stresses resulting in negative effects on their surface texture. To be more specific, static and dynamic loads are significant applied stresses on carpets, which leads to deformation of the surface texture. There are different tests used to assess the performance of carpets in terms of compressibility and resilience, the most important of which are thickness loss after brief moderate and heavy static loading tests [1-3].

Several studies and researches were accomplished regarding carpet performance measurement and the effects of manufacturing parameters. For instance, some researchers investigated the thickness loss under dynamic and static loading [4-7] while others studied the carpet performance under short and long term static loading [8-11]. Additionally, in the literature there are many studies on mechanical, physical and appearance properties of carpet [12-18].

Besides, in the literature, there are several studies which deal with the designs of different textile performance measurement systems. For instance, a measuring approach to examine the compression behavior of spacer fabrics was proposed by Mecit and Roye [19]. An instrument was developed by Fujimoto et al. to test and determine the surface friction of carpets and fabrics readily which enables to design pile products with high quality [20]. A new testing approach and a testing mechanism were proposed by Yao and Li through integrated assessment of fabric handle utilizing a virtual tool [21]. Li et al. proposed a testing approach to measure fabric touch feels [22]. Joshua et al.

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proposed a developed testing tool that is used for different lunar wheel tread material to test wear viability [23]. A measuring tool was proposed by Sengupta et al. to measure technical textiles in terms of bending behavior [24]. Alsayed et al. proposed a design of a test device to measure the performance of carpets in terms of resilience and compressibility [25, 26].

As it can be seen from the literature survey, the researchers are quite interested in static loading tests to evaluate the carpet performance. It is a fact that brief, moderate and prolonged heavy static loading tests are commonly preferred test methods. However, an automatic device that has the ability to measure the thickness and applies static loads on carpets has not been investigated yet. In this research, it is planned to create and manufacture a new and multipurpose test device in order to test thickness loss of carpet after the application of static loading and to store test data in a digital environment. The test device is fully automatic in terms of loading and unloading specimens, changing the loads, and recording test results as well without the intervention of an operator. Additionally, the developed test device is also capable of testing specimens that have a thicker structure, such as 3D fabrics.

MATERIAL AND METHOD

2.1 Definition of Need and Statement of Problem

The application of static loading tests requires a thickness measurement tool, in addition to the existence of a loading mechanism in order to determine the thickness loss caused by the loading process before and after recovery periods. Regarding the static loading test, firstly, by using the thickness measurement device, the thickness of the specimen is tested under 2 kPa pressure. Following that, according to the related standard, the specimen is exposed to a specific value of pressure for a specific period of time. Then, as soon as the loading period is completed, the load is removed and the specimen is kept without loading for a duration of time determined according to the standard. After that, the thickness is measured again. Eventually, the deformation that occurs due to the application of loads expresses the thickness loss of specimen. Determination of thickness loss can be obtained by two types of tests; prolonged heavy static loading and brief moderate static loading. For prolonged heavy static loading test, after the thickness is measured, 700 kPa load is applied for a time period of 24 hours on the specimen. Following that, the applied load is removed, and the specimen's thickness is measured after 2 minutes, 1 hour and 24 hours recovery periods [27, 28].

With respect to brief moderate static loading test, after the thickness of the carpet specimen is determined, an application of 220 kPa load for 2 hours takes place. Following the load application process, the carpet specimen left unloaded and thickness is determined in three intervals of time: after 15, 30, and 60 min. As a test requirement, five specimens must be tested for both static loading tests (heavy and brief moderate static loading) [29-31]. There are many difficulties to perform these tests. Several loading tools, and an additional carpet thickness measurement tool must be available in order to perform the previously mentioned tests. In fact, this will result in an important level of investment costs for users, such as research center, universities, and production plants as well. Additionally, both test processes are too complicated that cause personal faults due to manual equipments. Also, for the available manual test procedure it is not possible to securely record the test data in digital environment. There are several commercial brands which provide this type of manual carpet test devices [32, 35]. Today, it is a need to provide these time consuming and high labor tests automatically with a solo test device.

Table 1 provides a comparison between the commercially available test devices (A, B, C, D) and the newly developed test device (E) in terms of the capability of testing, drawbacks, and the control system.

Table 1. Comparison between the commercially available test devices (A, B, C, D) and the newly developed test device (E)

Test device	Capable of	Control system	Drawbacks
A	Applying static loads and testing thickness of carpet	Manual	Manual control Test results are not stored
B	Measuring carpet thickness, and underlay compression, and recovery	Manual	Manual control Test results are not stored automatically
C	Applying static loads	Manual	Additional tool is required to measure thickness Manual control Test results are not stored automatically
D	Testing recovery after applying a load for specific time	Manual	Additional tool is required to measure thickness Manual control Test results are not stored automatically
E	Measuring carpet thickness, application of brief and moderate and prolonged loading test	Automatic	None

The newly designed test device is superior to the commercially available test devices because of lower investment cost, decreasing the place requirement and automatically preforming the test and storing the data. Additionally, accurate and precise thickness measurements can be obtained since the tests are implemented automatically without intervention of an operator for loading and unloading samples and writing down the measurements of thickness, thereby the possibility of faults from the operator side can be decreased. Moreover, test results can be stored in a digital environment. Another advantage is that thicker textile material, such as 3D fabrics can be tested using the newly developed test device.

2.2. Design Requirement and Constraints

Several and essential issues of design requirements were studied and taken into consideration while designing the test device in order to have a reliable test device that is capable of providing accurate and precise measurement and following the related standards. The design requirements and constraints are:

i. The test device must have a presser foot with an area between 300 mm^2 and 1000 mm^2.
ii. The applied pressure must not have high fluctuation among the application duration.
iii. It must be ensured that the force on the specimen is identical at every part of specimen.
iv. The presser foot must move perpendicularly on the specimen and must run smoothly.
v. The component of the test device must be easy to manufacture (less number of moving components) and not expensive.
vi. The test device must be able to be controlled automatically.
vii. The structure of the test device must handle the forces which is identified in standards that are going to be applied during the static loading tests, such as 700 kPa.
viii. The usage of the test device must be easy and does not require skilled operator.
ix. The components of the test device must not make annoying sounds while working.
x. The test device must be equipped with a tool to ensure its balance before testing due to the importance of performing tests on a flat surface to achieve regular pressure on specimens.
xi. Test results should be able to be stored in a digital environment.
xii. The test device must be able to provide a low pressure on specimen such as 2 kPa for thickness measurements and a high pressure such as 220 kPa and 700 kPa for the static loading tests.
xiii. The test device must be equipped with a reliable load cell to measure the applied forces and ensure that the applied pressures are within the standards.
xiv. The test device must be adequate cost and affordable.
xv. The test device must be safe for users. Indeed, pneumatic systems have astounding advantages in terms of safety [36].

2.3. Design of Prototype Test Device

The working principle of the test device is based on receiving instructions from an interface of Arduino. A USB connection between Arduino and the laptop is used to control each component of the test device.

In terms of the synchronization of components, the test initializes when the solenoid receives a command to be opened, from the main controller, then the piston moves down due to the provided air from the air pressure regulator and the piston presses on the sample through its presser foot. The piston applies the required loads on the sample. The value of the applied load is detected previously using the load cell which is equipped to the test device.

The position sensor, which is attached to the piston, plays an essential role in determining the stroke of the piston continually. With the help of the position sensor, the thickness of the sample is measured. All the obtained measurements are stored and displayed in the interface of Arduino software. The scenarios of the tests that the newly developed test device is capable of implementing are shown in Figure 1.

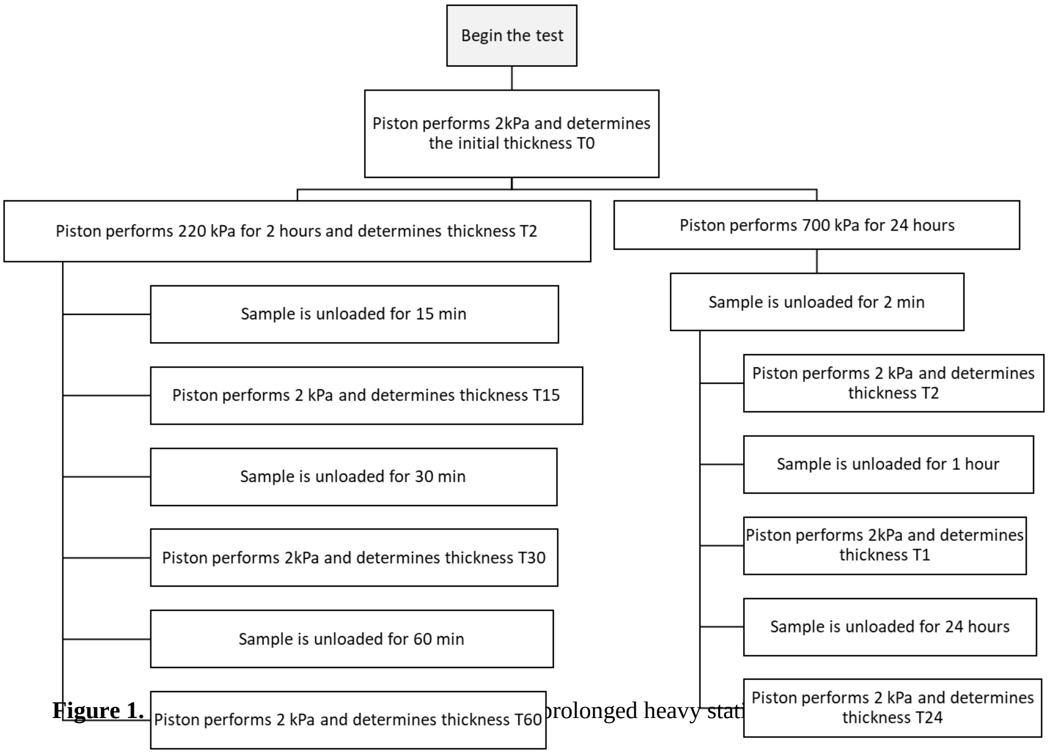

Figure 1. prolonged heavy stat

The diagram in Figure 2, represents the control block diagram of the newly developed test device.

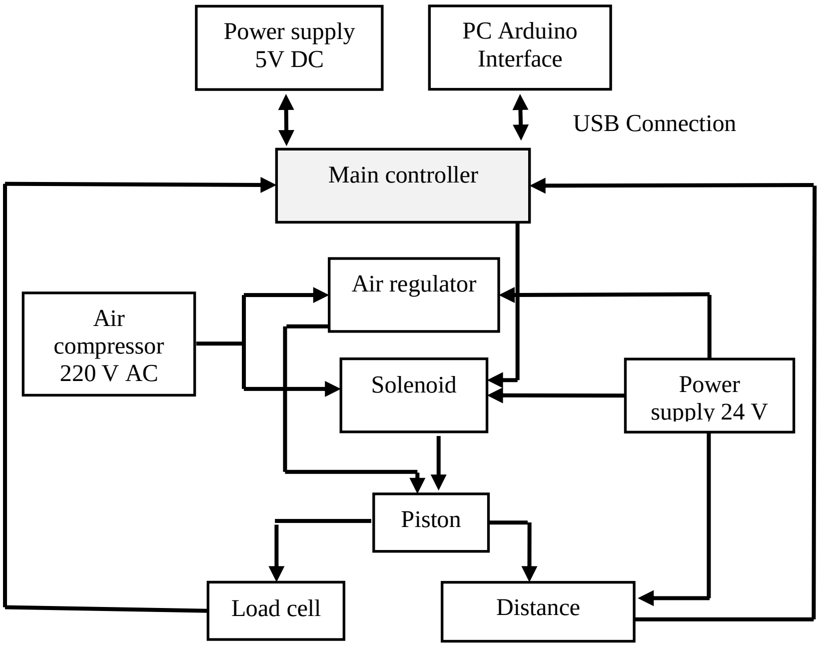

Figure 2. Block diagram of the communication in the testing process.

The main controller is the center of the control circuit. By the cooperation between the main controller and the position sensor, the thickness of carpet samples is measured.

As it is explained in Figure 2, the main controller sends orders to the pressure regulator and solenoid to control the movement of the piston and the amount of the pressure that will be applied. At the same time, the main controller receives data from the position sensor and the load cell and shows them in the interface of Arduino. The circuit is equipped with two power supplies; 5V DC for the microcontroller and 220V DC for the pressure regulator, position sensor, and solenoid.

Regarding the movement system of the piston, it moves linearly and perpendicularly on to the device base. The piston has 9 cm stroke and makes this stroke in 1 second.

The moving component of the mechanism is the piston, and its degree of freedom is 1 since the piston is able to move linearly in one direction (up and down).

The two-position and three-way 3/2 pneumatic solenoid valve is the in charge of determining the movement direction. 3/2 means two working positions and three ports in the piston body, namely 1 the inlet port, 2 and 3 are the outlet ports. The inlet port 1 is where the air is supplied to the valve, port 2 is where the supplied air pushes the piston, and port 3 is where the exhausted air goes outside the circuit. When the circuit is closed, the solenoid allows the air to go to the upper part of the piston, thereby the pressure of air P1 becomes bigger than the pressure of air in the lower part of the piston P2, thereby the piston goes down, and vice versa.

2.4. Construction of Prototype Test Device

The external body holds the components of the test device and maintains the conditions of the experiment balance. The body was made of durable metal to handle the loads that the test device applies. The process of manufacturing was accomplished using laser cutting technique to obtain clean edges. Basically, the external body has four screws and hex nuts that ensure and guarantee the balance of the test device by calibrating them before conducting tests. The dimension of the base of the external body is 29.5 cm × 40.7 cm × 5.0 cm. Figure 3 shows the photographic view of the newly designed test device and its components.

2. RESULTS AND DISCUSSION

3.1. Verification of the Test Device

As the newly developed test device applies static tests according to standards published by International Standardization Organizations, thereby, there is no change planned to the applied method. Only the principle of application of static loading with previously accepted devices is changed, which means that a new method is not implemented by the developed test device. Therefore, there is no need for a validation procedure. However, the verification procedure is necessary. The verification procedure is a procedure that does not contain as many details as the validation procedure, but it makes significant determinations. For the verification procedure, the accuracy criterion of the thickness measurement is taken into consideration. The accuracy criterion is determined by identifying trueness and precision. In order to verify the newly developed test device regarding trueness, the thickness measurements of the newly designed test device and a reference test device are compared and the difference between them is measured. While precision is measured by testing samples under repeatable and reproducible conditions [37, 38]. Two different samples; a cut-pile carpet and a loop-pile carpet were used as samples for the verification procedure. Table 2 exhibits the applied tests for the verification process of the newly test device

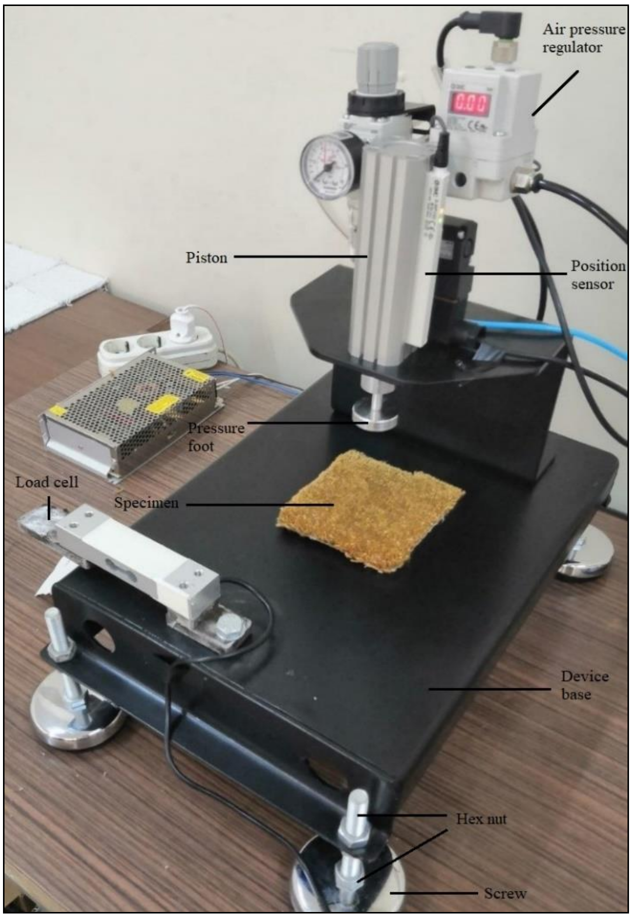

Figure 3. Photographic view of the newly designed test device

3.1.1 Determination of Trueness by Using Reference Method

To prepare the samples for testing, 15 specimens 10*10 cm from each sample were cut and conditioned in the laboratory for 24 h. The measurements of thickness were made utilizing the newly developed test device and the carpet thickness tester (as a reference). The test results are presented in Table 3.

To analyze the obtained data using SPSS, firstly, normality test was carried out, it was revealed that the findings are normally distributed. Accordingly, paired-Sample t-test was conducted. The results of the data analysis of test are shown in Table 4. The findings of the data analysis prove that statistically there is no significant difference between the thickness measurements of carpet thickness tester and the newly designed test device since Sig. (2. Tailed) = 0.728 > 0.05.

3.1.2. Determination of Repeatability

In order to determine the repeatability of the test device, the thickness of the same sample was measured three times in one-day duration. The test results are shown in Table 5. Following that, statistical analyses were carried out to determine the statistical significance between groups. Thickness measurements and statistical analyses were accomplished for both cut-pile and loop-pile sample.

Table 2. Verification procedure of the newly developed test device

	Test done by	Number of samples	Number of measurements	Purpose of procedure
1	Newly developed test device + carpet thickness tester	2	30	Determination of trueness by using reference method
2	Newly developed test device	2	30	Determination of repeatability
3	Newly developed test device	2	30	Determination of reproducibility over a long time period
4	Newly developed test device	2	30	Determination of reproducibility by different analysts

Table 3. Thickness measurement results of samples for determination of trueness

Specimen	Cut-pile sample		Loop-pile sample	
	Carpet thickness tester	Newly developed test device	Carpet thickness tester	Newly developed test device
1	14.28	14.50	7.04	7.16
2	14.23	14.36	7.06	7.43
3	14.61	14.55	7.23	7.42
4	14.55	14.51	6.81	7.1
5	14.56	14.85	7.2	7.16
6	14.25	14.03	7.25	7.23
7	14.76	14.91	7.5	7.24
8	14.67	14.70	6.86	6.81
9	14.54	14.35	6.85	7.27
10	14.67	14.40	6.82	7.34
11	14.47	14.40	7.25	7.41
12	14.74	14.71	7.12	7.06
13	14.88	14.92	6.98	7.13
14	14.40	14.16	7.4	6.84
15	14.76	14.66	7.14	7.13
Average	14.56	14.53	7.10	7.18
Standard deviation	0.20	0.26	0.21	0.19

Table 4. The results of Paired-Samples Test

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
SDL Atlas-Prototype	-0.025	0.078	0.055	-0.723	0.678	-0.455	1	0.728

Table 5. Thickness measurement results of cut-pile and loop-pile samples for determination of repeatability

Sample	Specimen	Measurement 1	Measurement 2	Measurement 3
Cut-pile	1	14.38	14.14	14.53
	2	14.39	14.73	14.59
	3	14.47	14.63	14.75
	4	14.58	14.52	14.31
	5	14.57	14.59	14.54
Loop-pile	1	7.10	6.96	7.11
	2	6.83	7.02	6.51
	3	7.46	7.21	7.54
	4	7.21	6.98	7.10
	5	7.18	7.35	7.39

In order to analyze repeatability of the newly developed test device, ANOVA was conducted for thickness measurements of each sample separately. The results of statistical analyses of cut-pile and loop-pile sample thickness measurements are provided in Table 6. The values of cut-pile and loop-pile thickness measurements are normally distributed. The results of the ANOVA show that statistically there is no difference in thickness measurement between the groups of the two samples at the three rounds of testing as the significance level of cut-pile and loop-pile sample 0.823 and 0.958 > 0.05, respectively.

3.1.3. Determination of Reproducibility over Long Time Period

Determination of reproducibility over long time period was done utilizing 15 specimens from each sample. The test was held for 3 days. Each day, 15 specimens from each sample were tested. The test results are given below in the Table 7.

Following thickness measurements, ANOVA was carried out to analyze the obtained test results. The results of statistical analysis of cut-pile and loop-pile carpet thickness measurements are presented in Table 8. It was found that the values of thickness measurement are normally distributed and statistically there is no significant difference between thickness measurement of the cut-pile and loop-pile samples over three days of testing as the significance level of cut-pile and loop-pile sample is 0.888 and 0.624 > 0.05, respectively.

3.1.4. Determination of Reproducibility by Different Analysts

In order to determine the reproducibility of the test device by different analysts, thickness measurements of fifteen specimens from each sample were tested by different analysts. For this aim, three technologists participated in this test. Each technologist tested 15 specimens from each sample using the newly developed test device. Table 9 represents the test results of test.

Table 6. ANOVA results for cut-pile and loop-pile samples

Sample		ANOVA				
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Cut-pile	Between Groups	0.011	2	0.006	0.199	0.823
	Within Groups	0.341	12	0.028		
	Total	0.353	14			
Loop-pile	Between Groups	0.007	2	0.003	0.043	0.958
	Within Groups	0.942	12	0.078		
	Total	0.948	14			

Table 7 Thickness measurements of samples for reproducibility over long time period

	Cut-pile sample			Loop-pile sample		
Specimen	**Day 1**	**Day 2**	**Day 3**	**Day 1**	**Day 2**	**Day 3**
1	14.32	14.34	14.76	7.77	6.98	7.20
2	14.38	14.45	14.55	6.78	7.00	6.96
3	14.39	14.24	14.67	7.13	7.43	7.37
4	14.47	14.43	15.12	7.15	7.46	7.43
5	14.51	14.68	14.61	6.94	7.27	7.43
6	14.59	14.16	14.45	7.06	7.57	7.50
7	14.70	14.86	14.14	7.64	7.84	6.99
8	14.55	14.22	14.20	7.66	6.97	6.98
9	14.53	14.63	14.51	7.39	7.30	7.10
10	14.66	14.63	14.81	6.73	7.22	7.20
11	14.50	14.62	14.82	6.82	6.95	6.98
12	14.78	14.56	14.65	7.37	7.37	7.55
13	14.42	14.77	13.97	7.20	6.96	7.14
14	14.73	14.49	14.78	6.82	6.99	7.19
15	14.67	14.75	14.39	6.95	7.60	7.04
Average	14.55	14.52	14.56	7.16	7.26	7.20

Table 8. ANOVA results for cut-pile and loop-pile samples

Sample		ANOVA				
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Cut-pile	Between Groups	0.012	2	0.006	0.119	0.888
	Within Groups	2.160	42	0.051		
	Total	2.172	44			
Loop-pile	Between Groups	0.075	2	0.038	0.477	0.624
	Within Groups	3.321	42	0.079		
	Total	3.397	44			

Table 9. Thickness measurement results of cut-pile and loop-pile samples for determination of reproducibility by different analyst

Sample	Specimen	Thickness measurements		
		Analyst 1	Analyst 2	Analyst 3
Cut-pile	1	14.45	14.50	14.38
	2	14.60	14.45	14.13
	3	14.24	14.17	14.83
	4	14.52	14.39	14.63
	5	14.57	14.72	14.81
	6	14.14	14.77	14.83
	7	14.87	14.67	14.79
	8	14.55	14.17	14.43
	9	14.49	14.83	14.38
	10	14.59	14.9	14.73
	11	14.47	14.89	14.67
	12	14.50	14.63	14.75
	13	14.89	14.73	14.73
	14	14.29	14.63	14.29
	15	14.54	14.40	14.34
Loop-pile	1	7.25	7.40	7.72
	2	7.07	7.09	7.22
	3	7.25	7.28	7.20
	4	7.94	7.07	6.66
	5	7.17	7.56	7.79
	6	6.92	7.16	6.86
	7	7.02	7.67	7.04
	8	6.98	7.17	7.50
	9	7.10	6.99	7.43
	10	7.43	7.26	7.06
	11	7.32	7.21	7.21
	12	7.47	7.50	7.08
	13	7.00	7.33	7.55
	14	6.97	7.34	6.91
	15	6.83	7.20	7.46

ANOVA was carried out to analyze the obtained data. The statistical analysis of the thickness measurements of the cut-pile and the loop-pile carpet samples was accomplished separately. The results of the data analysis are exhibited in Table 10. The data is distributing normally. As the findings of ANOVA show that, statistically, there is no significant difference between the thickness measurement of the technicians as the significance level is found to be 0.597 and 0.591> 0.05 for cut-pile and loop-pile, respectively.

Table 10. ANOVA results for cut-pile and loop-pile samples

Sample		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
Cut-pile	Between Groups	0.052	2	0.026	0.522	0.597
	Within Groups	2.090	42	0.050		
	Total	2.142	44			
Loop-pile	Between Groups	0.078	2	0.039	0.533	0.591
	Within Groups	3.077	42	0.073		
	Total	3.155	44			

3. CONCLUSION

The purpose of this study is designing and manufacturing a multifunctional, innovative, automatic, and solo test device that has the ability of measuring thickness loss after static loading and storing test result in a digital environment. Following the design process, the newly test device was manufactured and a verification process was carried out to know whether the test device is able to accurately measure the thickness of samples. In the precision measurement, repeatability and reproducibility were applied. Regarding repeatability, thickness of the carpet samples was measured under repeatability conditions while thickness measurement of the carpet samples for reproducibility procedure was carried out under two conditions as; a long period of time and by different analysts, and by one analyst at different time intervals. This research concentrated on thickness measurements, and the applied load, 2kPa, was determined using a load cell. For future work, the code for both brief moderate loading test and prolonged loading test should be written and identified for system. Following that, brief moderate loading test and prolonged loading test should be implemented utilizing the newly developed test device and a reference test device for verification.

By using the SPSS software, the ANOVA was conducted. It was found that for the cut-pile sample, statistically, there is no significant difference between the thickness measurement of the technicians as the Sig. is found to be 0.597 > 0.05. In regard to the loop-pile sample, the Sig. was found to be 0.591 > 0.05, which means that the newly developed test device meets the reproducibility conditions. The statistical results revealed that the new test device has repeatability and reproducibility conditions.

As a conclusion the newly developed test device provides true and precise thickness measurements and is capable of applying all the required loads for thickness measurement test, brief, moderate static loading test, and prolonged heavy static loading test. Moreover, the repeatability and reproducibility conditions are met using the test device. Therefore, the newly designed test device is considered an effective, accurate, precise and verified test device that can be used for its advantage which can be concluded as; accurately measuring the thickness of carpets, a solo test device that can apply the static loading tests, all the test are automatically conducted without an intervention from the side of operator. Additionally, test results can be stored automatically.

In the scope of this study, the used samples for testing are two different types of carpets. For future work, other type of textile materials can be tested, such us nonwoven fabrics, 3D fabrics, etc.

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