AUGUST 2020 M.Sc. in Textile Engineering MAHER ALSAYED

REPUBLIC OF TURKEY
GAZİANTEP UNIVERSITY
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

# DEVELOPMENT OF A FUNCTIONAL TEST DEVICE CAPABLE OF AUTOMATICALLY PERFORMING MAIN CARPET PERFORMANCE TESTS

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MAHER ALSAYED
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**M.Sc. Thesis**

**in**

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**Gaziantep University**

**Supervisor**

**Assoc. Prof. Dr. Hatice Kübra KAYNAK**

**Co-Supervisor**

**Assoc. Prof. Dr. Halil İbrahim ÇELİK**

**by**

**Maher ALSAYED**

**August 2020**

**I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.**

**Maher ALSAYED**

## ABSTRACT

## DEVELOPMENT OF A FUNCTIONAL TEST DEVICE CAPABLE OF AUTOMATICALLY PERFORMING MAIN CARPET PERFORMANCE TESTS

**ALSAYED, Maher**
**M.Sc. in Textile Engineering**
**Supervisor: Assoc. Prof. Dr. Hatice Kübra KAYNAK**
**Co-Supervisor: Assoc. Prof. Dr. Halil İbrahim ÇELİK**
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The quality of carpet is evaluated according to their resistance to texture deformation. The most important factors affecting the texture deformation of carpet are static loads causing the compression of carpet pile yarns. There are two types of tests to determine the compressibility and resilience performance of carpets namely; thickness loss after prolonged heavy static loading and thickness loss after brief moderate static loading. Today, for these tests, thickness measurement device and static loading apparatus are used which are controlled manually. The present state has disadvantages of using different apparatus which increase the investment costs, performing of tests manually which cause personal faults and inability of storing test data in digital environment. Today, it is a need to provide these time consuming and high labor tests automatically with a solo test device. In this study, three different designs of a new prototype test device were made, studied and compared. Among them, the most appropriate one according to design criteria was selected. The newly designed test device is capable of performing carpet thickness measurement, brief moderate static loading and prolonged heavy static loading tests automatically. Finally, verification of the newly designed test device was demonstrated by measuring the accuracy of thickness measurement. For this aim a series of statistical analyses were done at 95% confidence interval. Consequently, the newly designed test device verified as providing repeatable and reproduceable carpet thickness measurements.



**Key Words:** Carpet, Resilience, Static Loading, Machine Design, Automatic Control

# ÖZET

## BAŞLICA HALI PERFORMANS TESTLERİNİN OTOMATİK OLARAK UYGULANABİLECEĞİ FONKSİYONEL BİR TEST CİHAZİNİN GELİŞTİRİLMESİ

**ALSAYED, Maher**
**Yüksek Lisans Tezi, Tekstil Mühendisliği**
**Danışman: Doç. Dr. Hatice Kübra KAYNAK**
**İkinci Danışman: Doç. Dr. Halil İbrahim ÇELİK**
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**66 sayfa**

Halıların kalitesi, yüzey deformasyonuna karşı gösterdiği dirence göre değerlendirilmektedir. Halıların yüzey deformasyonunu etkileyen en önemli faktörler, halı hav ipliklerinin sıkıştırılmasına sebep olan statik yüklemelerdir. Halıların sıkıştırılabilirlik ve rezilyans performansını belirlemek için iki tür test kullanılmaktadır. Bunlar; uzun süreli ağır statik yüklemeden sonra kalınlık kaybı ve kısa süreli orta statik yüklemeden sonra kalınlık kaybı tayinidir. Günümüzde bu testler için manuel olarak kontrol edilen kalınlık ölçüm cihazı ve statik yükleme aparatları kullanılmaktadır. Mevcut durum, yatırım maliyetlerini artıran farklı ekipmanların kullanılması, testlerin el ile yapılmasından kaynaklı hataların yaşanması ve test verilerinin dijital ortamda depolanamaması gibi dezavantajlara sahiptir. Günümüzde zaman kaybına neden olan bu işçilikli testlerin tek bir test cihazı ile yapılabilmesi bir ihtiyaçtır. Bu çalışmada, yeni bir prototip test cihazının üç farklı tasarımı yapılmış, incelenmiş ve karşılaştırılmıştır. Yeni tasarlanan test cihazı, halı kalınlığı ölçümü, kısa orta statik yükleme ve uzun süreli ağır statik yükleme testlerini otomatik olarak gerçekleştirebilmektedir. Son olarak, üretilen prototip cihazın doğrulaması için kalınlık ölçümünün doğruluğu saptanmıştır. Bu amaçla, % 95 güven aralığında bir dizi istatistiksel analiz yapılmıştır. Sonuç olarak, yeni tasarlanan test cihazının tekrarlanabilir ve yeniden üretilebilir halı kalınlığı ölçümleri sağladığı doğrulanmıştır.

**Anahtar Kelimeler:** Halı, Rezilyans, Statik Yükleme, Makine Tasarımı, Otomatik Kontrolü

This thesis is dedicated to the soul of my father and mother who have taught me every thing and who are my role models of my life and who have always been a source of inspiration and encouragement. To my great brothers who I love the most, to my faithful friends, and to my country Syria with all the warm wishes of peace and to my second country Turkey.

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# CHAPTER I

# INTRODUCTION

## 1.1 Introduction

Carpets are commonly used textile materials by people in their living areas. They are not only used to provide sound and heat insulation but also for aesthetic appearance in houses, hotels, conference rooms, etc. [1].

Carpets are exposed to many stresses during usage which adversely affect their surface texture. Some of the influential stresses are static and dynamic loads. These loads cause a texture deterioration on floor covering surface. The most commonly used tests to assess the compressibility and resilience performance of floor coverings are thickness loss after brief moderate static loading and prolonged heavy static loading [1-3].

In static loading tests, a floor covering thickness measurement device and a loading mechanism are required for determination of thickness differences before and after the loading and recovery periods. For static loading tests, at first sight, the thickness of the specimen is measured under 2 kPa pressure by the thickness measurement device, then the specimen is loaded with the required value of pressure and duration according to the related standard. After the loading period, the specimen is maintained unloaded for a specific time period according to the standard and after that the thickness is measured again. The deformation of the specimen is stated as the thickness loss. According to the available standards, for prolonged heavy static loading test, the thickness of the carpet is measured by the thickness measurement test device, then the carpet specimen is loaded for 24 hours under 700 kPa load. After this period, the load is removed and the thickness of the specimen is measured 2 min later. After that, the carpet is unloaded and the thickness is remeasured after a recovery period of 1 h and 24 h under 2 kPa at the same place of compressed area [5, 6]. Similarly, for brief moderate static loading test, at first sight, the thickness of the specimen is measured by the thickness measurement device, then 220 kPa load is applied for 2 hours. At the end of 2 hours load application period, the thickness of the specimen is measured under 220 kPa load. After the loading process is completed, the specimen is remained unloaded. The thickness of the specimen is measured for 15 minutes, 30 minutes, and 60 minutes recovery periods. Testing of five specimens is essential for both static loading tests. The required time for testing one sample of carpet for the brief, moderate static loading is 10-10.5 hours, whereas it is 48 hours for prolonged heavy static loading [4, 7, 8]. For each of the aforementioned tests, a carpet thickness measurement device and a different loading apparatus are required. This situation causes important investment costs for scientific and production mill laboratories. Different brands of carpet test devices are available, either national or imported [9-12].

Furthermore, it is very laborious to follow up the both test procedure for an operator. The procedure is prone to personal operator faults. Consequently, it should be more convenient to make these tests by a solo test device by eliminating the probable operator faults and by decreasing the investment cost of laboratories. ***In this study, it is aimed to design and manufacture a multi-functional and innovative test device for measurement of thickness loss after static loading tests by using an automatic solo test device that has the ability 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 samples of thicker materials such as 3D fabrics.***

## 1.2 Literature Survey

Several studies and researches were accomplished regarding carpet performance measurement and manufacturing parameters of designs and carpet test devices. For instance, Celik (2010) investigated the thickness loss of Wilton type carpets under dynamic loading. For this purpose, three Wilton type piled carpets were produced. The samples were made of acrylic, wool, and polypropylene. The carpet samples were designed differently with regard to the pile density, the pile material, and the weft density. The samples were tested under dynamic loads to evaluate and study deformation and thickness loss of carpet against dynamic loads. According to test results, acrylic carpet has more capability of recovery after dynamic loads compared to other carpets tested. On the other hand, the wool carpet was found to have the worst recovery performance regarding the dynamic loads [13].

Küçük and Korkmaz (2016) investigated sound absorption properties of acrylic carpets. For this purpose, acrylic carpet samples with different physical parameters were used. The samples had four different pile heights and two different pile densities and were produced by Wilton face-to-face weaving method. Sound absorption properties were tested at different sound frequency levels. According to results, acrylic carpets with medium length piles and low-density loops provided better results at higher frequencies. High frequency sound waves are accompanied with the shorter wave lengths. The carpet samples that had shorter piles and dense loops were found to be better in sound absorption especially at the mid frequencies. The best sound absorption rates were obtained in acrylic carpets that had longer piles and dense loops. At all frequencies, loop density and pile height were found to be effectual [14].

Javidpanah et al. (2014) investigated thickness loss of cut-pile carpet under static loading. The carpet was produced using heat process-modified polyester pile yarn. For this purpose, four types of air-jet textured polyester pile yarn (ATY) were made including the normal polyester ATY yarn, and three polyester ATY yarns which were exposed to heat processing involving: heat-setting, frieze process, and twist-setting treatments. According to results, the processes of friezing and heat-setting of polyester filament pile yarns have no critical impact on the carpet pile recovery. On the other hand, treating carpet pile yarns with twist heat-setting at higher temperature increased the carpet recovery since the twist heat-set pile yarns has better resilience at longer relaxation times [15].

Javidpanah et al. (2014) investigated the thickness loss property of cut-pile carpet under dynamic loading. Samples were produced using heat process-modified polyester pile yarns. For this purpose, carpet polyester pile yarns with four different types were made as normal ATY polyester carpet pile yarn and three other types of pile yarn were modified by three different heat processes after production; Frieze treatment, heat setting, and twist-setting treatment. The pile yarns were exposed to this heating treatment in order to investigate the effect of changing the twist heat-setting temperature on carpet pile yarn recovery. The results show that heat processing of polyester pile yarn has no significant effect on carpet pile recovery after dynamic loading [16].

Korkmaz and Kocer (2009) investigated woven acrylic carpets in terms of resilience behavior under short- and long-term static loading. The effects of pile height and pile density on carpet static loading were investigated. The results show that the pile height is considered as the most essential factor that immediately affect carpet thickness loss after 2-hour loading. Regarding short-term loading, the samples showed very remarkable resilience in the first 15 minutes. However, after the recovery periods of 30 and 60 minutes, the amount of resilience decreased [17].

Koc et al. (2007) investigated thickness loss after prolonged heavy static loading of Wilton-type carpet samples that are produced with different pile materials namely; wool, acrylic and polypropylene. For this purpose, pile material, weft density and pile density of the carpet samples were changed. The results showed that for all carpet samples, when the recovery period is longer, better resilience levels occur. The acrylic sample exhibited the lowest resistance to static loading while the wool sample is moderate and the PP sample provided the highest resistance. In terms of permanent deformation Dp, wool carpet is the most outstanding and the acrylic carpet is the worst [18].

Korkmaz and Dalcı Kocer (2010) investigated the effects of the production parameters of polypropylene carpets on carpet performance. For this purpose, eight Wilton type face-to-face carpet samples which had two different pile densities with four different pile heights were used. The results show that as the pile height increases, the appearance retention decreases. Thickness loss increases in carpets with low pile densities and vice versa [19].

Çelik (2017) investigated the effects of fiber linear density on acrylic carpet performance. For this purpose, three Wilton type face-to-face cut-pile carpet samples were produced. As for pile, acrylic yarns of 2.75, 6, and 8 denier fiber linear densities were used. The results showed that the fibers with 2.75 denier had the lowest loose fiber ratio. Regarding acrylic carpets, by using finer fibers, the decrease of loose fibers and pilling on the carpet surface was available due to the foot traffic. It was observed that for the static loading test, the carpet sample with 2.75 denier fibers show the highest thickness loss values and resilience. The resilience of the pile yarn and the recovery capability after compression can be enhanced using finer fibers. The lowest thickness loss value and the highest compression recovery value were obtained with the sample that has 8 denier fiber linear density. Additionally, as the fibers get coarser, compression performance were observed to be better [20].

Erdoğan (2012) investigated the resilience property of polypropylene carpets in terms of the effect of pile fiber cross-sectional shape. For this purpose, Wilton face-to-face carpet samples were produced. Trilobal polypropylene (PP-T) and hollow polypropylene (PP-H) of BCF yarns were used as pile yarn. Filling density, warp density, pile height, and pile density were constant. The results show that carpets with hollow piles were found to be better than carpets with trilobal piles in short- and long-term static loadings. On the other hand, in terms of recovery, in short-term static loading, compression was higher in carpets with trilobal cross-sectioned fibers. However, for the long-term static loading, compression was higher in carpets with hollow cross-sectioned fibers [21].

Çelik et al. (2009) investigated the performance properties of Wilton-type carpets with relief texture produced by shrinkable high bulk (HB) and relaxed acrylic (RX) pile yarns. To achieve that two carpet samples; high bulk HB acrylic yarn and relaxed acrylic (RX) acrylic yarn were produced. The samples were produced in the same production properties except for pile yarn, where linear density of pile yarn, pile density, weave structure, and warp and weft density were the same for samples. The results showed that (HB) acrylic samples were found have higher pile withdrawal force. The durability property of (HB) acrylic and (RX) acrylic was the same and they showed similar behavior in terms of thickness loss after brief moderate static, and prolonged heavy static loading as well [22].

Özdil and Bozdoğan (2012) investigated thickness recovery and compressibility characteristics of carpets made of acrylic, polypropylene, and wool yarns. It was found that the pile characteristics and the material type have an effect on carpets in terms of compressibility and recovery properties. It was found that for acrylic carpet samples when thicker pile yarn used, the thickness loss values were lower in static and dynamic loading tests. For static and dynamic loading tests, wool carpets were found to have higher compressibility and lower recovery percentage than acrylic carpets [23].

Dayiary et al. (2010) verified theoretical approaches practically to predict carpet compression through measuring the total energy of pile deformation of the samples. The compression property was measured. For this purpose, fifteen face to face carpet samples with three types of pile yarns; polypropylene BCF, heat set polypropylene BCF, and acrylic spun yarns, and with five level of pile yarn densities were produced. The results show that the theoretical approaches can accurately predict the compression of carpets [24].

Mirjalili and Sharzehee (2005) investigated the effect of fibers fineness, tanning process, and knot density on mechanical and physical properties of hand-woven carpets under static loads. For this purpose, eight samples of woven carpets with two different wool fibers, Sirian and Kermanshah from two difference regions in Iran were used. From each region conventional and tanned wool fibers were chosen. The samples were dyed by vegetable dyestuff. The results showed that the time was a major parameter affecting thickness loss of the carpets under static load. The thickness loss of the carpets, having higher knot density, was less compared with carpets having lower knot density. The knot density of the carpet was affecting the pile recovery carpets, where the pile recovery of the carpet with lower knot density was higher than the similar carpet with high knot density [25].

Moghassem et al. (2012) investigated two soft computing modules to predict thickness loss of Persian carpets. Two soft computing modules methodologies (Artificial Neural Network models) ANN and Gene Expression Programming (GEP Algorithm) were presented in this study. For this purpose, eighteen hand-knotted carpet samples were produced with three variables; number of knots, initial thickness, and the amount of slipe wool in pile yarn. The results showed that ANN model and GEP algorithm were effective tools to predict thickness loss of hand-knotted samples, in addition, GEP had the advantage of providing mathematic equation that can help in the production process [26].

Vuruşkan (2017) investigated the fiber mobility of Wilton woven carpets made of acrylic in terms of fiber loss under traffic wear. The samples were produced with different pile density and height. For this purpose, twelve samples of Wilton cut-pile carpet samples with four levels of pile density and three levels of pile height were produced and considered. The acrylic pile yarns had 6.5 denier linear density. The results showed that pile density and pile height have a significant effect on fiber loss and as the pile density and pile height increase, fiber loss decreases [27].

Watson and Warnock (2003) investigated the physical characteristics and appearance retention of recycled and newly manufactured carpets. For this purpose, the physical characteristics of four types of carpets; recycled polyester, recycled nylon, newly produced polyester, and newly produced nylon were tested after and before applying Tetrapod Walker and soiling. The results showed that the recycled polyester and nylon carpets are as good as the newly produced carpets, in some cases the recycled carpets are better. In terms of color change, the recycled polyester carpets showed less color change comparing with the other types of carpets along with maintaining the original tufts per inch and also it showed better compression and recovery yarn structure properties than the others [28].

Babaarslan et al. (2017) investigated the effect of fiber blend ratio on compressibility and resiliency properties of Wilton woven carpets. For this purpose, five different Wilton carpet samples with different pile yarn fiber blend ratio were produced by keeping the other production parameters same. The samples were made of viscose and acrylic fibers. Then the compressibility test was applied. The results showed that the samples with more than 50% of acrylic fibers have more resistance to deformation under pressure. In addition, the higher percentage of acrylic fibers was concluded to play an important role in enhancing compressibility [29].

Radhakrishnaiah (2005) investigated the performance properties of carpet samples made of nylon 6 and nylon 66. For this purpose, 24 carpet samples, 12 of them made of nylon 6 yarns, and the remaining samples were made of nylon 66 yarns, were produced. The yarns were similar in terms of fiber cross section, filament denier and yarn denier. The results showed that carpets made of nylon 66 are superior in terms of texture retention and colorfastness to ozone when comparing to nylon 6 carpets. There were no significant differences between nylon 6 and nylon 66 carpets regarding colorfastness to nitrous oxides, thickness recovery (when applying prolonged static loads), oil repellency, water repellency, and soil repellency. When nylon received fluoropolymer treatment, its water repellency, oil repellency and soil repellency properties enhanced considerably [30].

Sarioglu et al. (2017) investigated the effect of pile height and weight on woven carpet compression under dynamic loading. For this purpose, six acrylic cut-pile carpet samples were produced. The results showed that the pile height and density play an important role in the dynamic loading performance of carpets. A better compression property can be obtained using yarns with lower pile height. Also using pile yarns with high density can provide better compression results [31].

Hearle et al. (2005) presented a computational method in order to model carpet wear. The simulation results showed that the computational and analytical methods give results with similar accuracy. The computational model can deal with both group and individual fiber behavior [32].

Çelik and Bozoğlan (2019) presented a new approach for solving carpet pile pull out problem. For this reason, samples were produced with the same manufacturing conditions except for the weft yarns. Composite weft yarns by wrapping jute yarns with low-melt polymer and with different number of piles were produced then the samples were tested for pile withdrawal force and compression-recovery. After that, the obtained results of tests of the samples, which were produced with the new approach, were compared to samples that used the conventional method (standard latex application). It was found that the samples with the new approach have a higher pile withdrawal force than the conventional one. Additionally, the resilience performance of the samples with the developed method is higher than the conventional method (latex application) [33].

As it can be seen from the literature survey it is obviously seen that, the researchers are quite interested in static loading tests to evaluate the carpet performance. Both brief moderate and prolonged heavy static loading tests are commonly preferred test methods. So, it would be very beneficial to provide user friendly test devices to textile sector.

Besides, in the literature, there are some studies which deal with the designs of different textile performance measurement systems. Mecit and Roye presented a test method to investigate the compression behavior of spacer fabrics. It was concluded that the proposed testing way can be applied to measure the compression behavior of spacer fabrics [34]. Fujimoto et al. developed a sensor to measure the surface property of pile materials. The developed sensor was found to be able to quantify the friction that has previously been difficult to be measured [35]. Yao and Li presented a measurement system and new test method based on a virtual instrument for integrated evaluation of fabric handle [36]. A measurement method of fabric touch feels which named fabric touch tester was reported by Li et al. Four different modules namely; compression, thermal, bending, and surface were used to simultaneously measure the fabric touch feel, which significantly reduce the testing cost [37]. A developed testing equipment for determining the wear viability of various lunar wheel tread materials with service lives of up to ten years and 10000 km was presented by Joshua et al. [38]. Sengupta et al. presented a testing instrument for measuring bending behavior for technical textiles. The proposed instrument was able to test a wide range of fabrics with different thickness and structures. In addition, the developed instrument can be set for required speed and sample size [39].

However, a developed design that presents an automatic solo test device for thickness measurement and static load application for carpets has not been studied yet. The new test device will be capable of implementing the thickness measurement, brief moderate static loading and prolonged heavy static loading tests automatically without an intervention of an operator. Additionally, the place requirement and cost will be decreased considerably. Test results will be provided in a computer environment with the ability of data storage. Moreover, thicker materials such as 3D fabrics will be tested using the new test device.

### 1.3 Layout of Thesis

This thesis started with an introduction about the subjective of the study. In Chapter I, all the related and previous studies we re mentioned in detail. In addition, the importance of the research was emphasized. While Chapter II is concerned with the factors and forces that directly affect the appearance of carpets and cause undesirable consequences. Also, in Chapter II all the frequently used tests and standards for carpets in terms of recovery, compressibility, and thickness were explained in detail. Additionally, some of the most important commercially available test devices in the textile sector were mentioned and discussed thoroughly. Chapter III deals with the main reasons behind developing the test device and the design requirements. All the alternatives that were studied and assessed and the criteria of selection of the proper design are also mentioned in this Chapter. The manufacturing process and steps and the principle of operation of the test device are discussed extensively in Chapter IV. Moreover, the components of the test device and the functions are explained in order to present the requirement of designing for the test device. After that, the procedure of the verification process of the test device and the instructions and the required measurements to verify the newly test device were discussed in detail in Chapter V. In addition, the findings of the verification process and data analysis were presented in Chapter VI. Then the discussion and conclusion part were thoroughly discussed in Chapter VII. Also, the practical recommendations for future work were given in Chapter VII.

# CHAPTER II

## CARPET STATIC LOADING TESTS AND COMMERCIALLY AVAILABLE TEST DEVICES

Carpets are made of three groups of yarns; warp, weft, and pile, where the warp and weft yarns build the base of carpet and the pile yarns provide the surface of the carpet. For this reason, the pile yarns play an important role in determining the quality of carpets. There are two types of carpets in terms of manufacturing, the handmade carpets in which there is no electronic component in the process of manufacturing. There are three ways to manufacture handmade carpets: tufting, flat weaving, and knotting. The second type is machine-made carpets. There are many methods for producing machine-made carpets, such as weaving, tufting, knitting, braiding, etc. [40].

Carpets are exposed to rigorous treatment due to foot movement, furniture, dust…etc. Undoubtedly the appearance of carpet is very essential. When the appearance of carpet is adversely affected, it should be replaced and that is why the appearance retention of carpets is considered to be a very important quality parameter. Also, the durability of carpet plays an important role in the quality of carpet, it refers to the ability of a carpet to confront mechanical wear. The mechanical wear forms are several, such as walking, wheeling trolleys, castor chairs, dragging objects over the carpet, cleaning, etc. In addition, carpets are exposed to heavy static loads such as furniture.

The durability of carpet can be classified into three stages: Elastic mechanism (compression and compression recovery), Inelastic mechanism (flattening), and fatigue mechanism (abrasive pile loss) as described in Figure 2.1 [41].

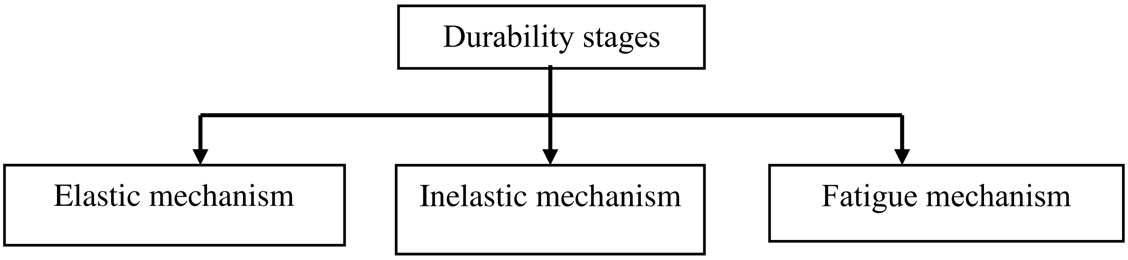



**Figure 2.1** Durability stages

Compression is defined as the change in the thickness of carpet while increasing pressure whereas compression recovery is described as the ability of the carpet pile to return to its initial state after deformation.

Pile bend mechanism is the pile yarn action under a compressive load. There are three phases in cut-pile carpet deformation. At the first stage, the load is applied as shown in Figure 2.2.A and Figure 2.2.B, position A presents the new carpet and B represents loaded carpet. Through the second stage, the pile changes from a bent shape into a shape having a flat part at the base and a curved part at the top as described in Figure 2.3.A. While at the third stage, the two sectional forms bend further leaning increases towards the base as shown in Figure 2.3.B.

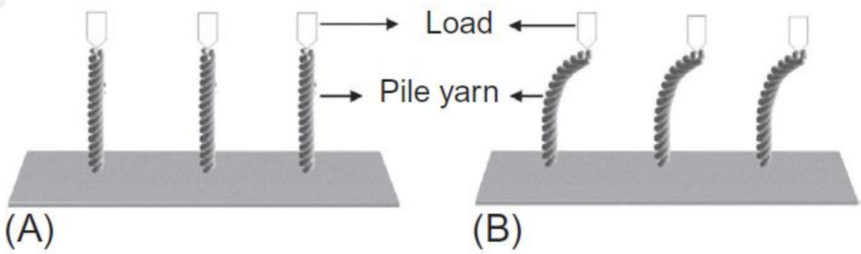
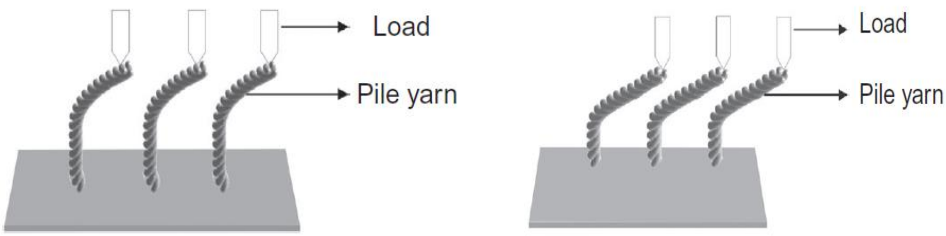



**Figure 2.2** Application of load [40]




**(A)** **(B)** [40]

**Figure 2.3** Pile deflection and pile deformation

To evaluate the appearance durability of carpet, many different tests should be performed. The most commonly applied carpet performance tests are; thickness loss after dynamic loading, thickness loss and recovery after static loading, tuft-withdrawal force, and abrasion resistance. This research focuses on designing and manufacturing of a test device capable of applying static loads and measuring thickness loss to analyse compression and recovery characteristics [40-42].

## 2.1 Static Loading Tests

### 2.1.1 Thickness Loss of Textile Floor Coverings after Prolonged Heavy Static Loading (ISO 3416, TS 7578, BS 4939)

The standards define a method to determine the thickness loss of carpets after prolonged heavy static loading. In this test, a carpet thickness tester and a static loading apparatus are used. The thickness tester which has a circular presser-foot with an area between 300 and 1000 $mm^2$ is able to measure thickness with an accuracy of 0.1mm at pressure $2.00 \pm 0.2$ kPa.

The apparatus consists of five alloy specimen plates 100×100×6 mm and a static loading machine that has the ability to apply a pressure of 700 kPa through the circular foot that has a radius of at least 2 mm greater than the radius of presser-foot of the tester.

The specimens should be conditioned according to the standard atmosphere ISO 139 for conditioning and testing textiles. To prepare specimens, five specimens with dimension of 100 mm×100 mm should be cut as it is clarified in the procedures of ISO 1957.

In order to prepare the test specimens, the four corners of a specimen plate should be attached across with a double-sided adhesive tape to guarantee adhesion, and should be compressed firmly. Measurements should be taken to the nearest 0.1 mm. The thickness *d1* of the plate in the centre at the standard pressure, and after removing any backing paper, a test specimen should be mounted by using surface uppermost on the prepared specimen plate, to ensure adhesion, corners should be pressed down adequately. Specimens should be conditioned in the standard atmosphere for at least 24 hours.

To start the test, the thickness of the specimen is measured at the standard pressure in the centre to get the total thickness of test specimen and plate *d2*. The measured specimen is placed on the static loading apparatus by taking into account that the presser-foot is central, then the needed pressure (700 kPa) is applied. It is left uninterrupted for 24 hours. The mounted specimen is removed from the static loading apparatus, it is placed on the thickness test device and the thickness of the assembly is remeasured within the compressed area after recovery period for 2 min. The thickness losses are measured at each stage (after a recovery period of 1 h and 24 h), for each specimen, to the nearest 0.1 mm. Figure 2.4 expresses the convenient static loading apparatus which covers the requirements. The apparatus includes a lever system, where:

A: Is a fixed pivot point (the beam is extended backwards for counter-weight C to balance the weight of the beam)

B: Is an iolite bearing constraining the circular presser-foot P to move in the vertical direction and apply the load to the test specimen [5].

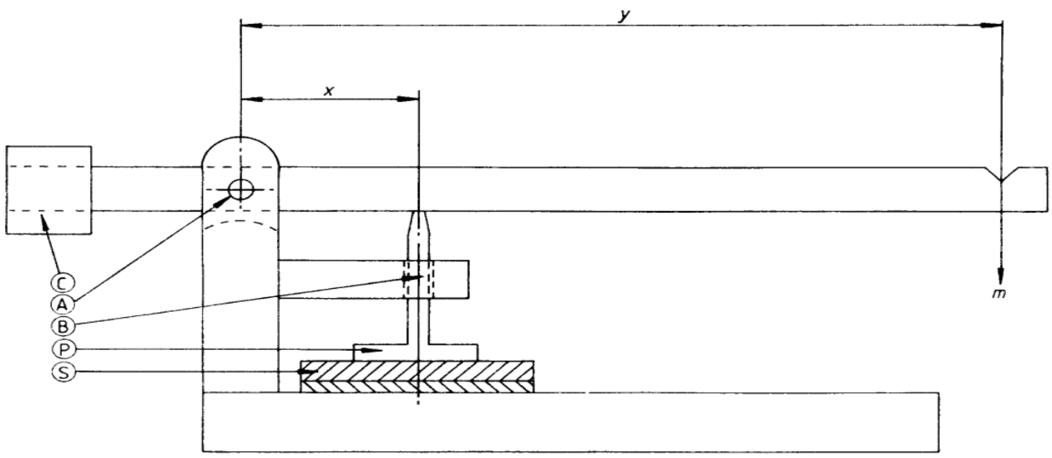



**Figure 2.4** Static loading apparatus [5]

The ratio *x/y* is selected so that mass m applies a pressure of 700 kPa on the circular presser-foot of area A $mm^2$:

The required mass that must be hanged on static loading apparatus can be calculated by means of equation 2.1.

$$m = 7\,A \times \frac{x}{y} \times 10^{-2}\ kg \tag{2.1}$$

According to this equation when $A$ 600 mm$^2$ and $x/y$ = 13/53. Then $m$ will be

$$m = 7\,A \times \frac{x}{y} \times 10^{-2} = 10.30 \text{ kg}$$

The weight of the test device when hanging the load is 10.30 kg.

### 2.1.2 Thickness Loss After Brief, Moderate Static Loading (TS 3378)

This standard presents an approach to determine the thickness loss of carpets after brief and moderate static loading. Static loading machine is able to apply pressure on specimens between 2kPa and 220kPa. The area of the presser-foot is between 300 mm$^2$ and 1000 mm$^2$. It is essential that the pressure applied by the presser-foot should be even on the specimen. For testing, each specimen should have the dimension of 250 mm × 250 mm and at least 5 specimens should be prepared.

In the test, the intial thickness of specimen, before applying pressure, should be determined under 2 kPa pressure according to the method in standard TS 3374. During the test, the specimen should not be touched and its place should not be changed, after the determination of the initial thickness, 220 kPa pressure should be applied smoothly on the specimen for two hours then the thickness should be determined under 220 kPa load. Then, the applied pressure should be removed without touching the specimen or changing its location and the thickness should be measured after (15 min, 30 min, and 60 min) recovery periods. For each specimen, the following calculation should be accomplished: the intitial thickness under the standard pressure (2kPa), the thickness under 220 kPa, the thickness of specimen after resting the specimen for 15 min, 30 min, and 60 min duration. The thickness loss is measured as (the intial thickness – the thickness under 220 kPa) and the thickness loss after resting is measured as (the intial thickness – the thickness after resting periods; 15 min, 30 min, and 60 min) [43].

### 2.1.3 Thickness of Textile Floor Coverings (ISO 1765, TS 3374, BS 4051)

This standard presents an approach to determine thickness of carpets. The instrument for measuring the thickness has a circular plane presser-foot with an area between 300 and 1000 mm$^2$. The presser-foot should have the ability of applying a pressure of 2.0 ± 0.2 kPa on specimen, and also determining the thickness of specimen with an accuracy of 0,1 mm over a range of 25 mm. The reference plate where the specimen is being placed should be plane and has the dimension of 150 mm × 150 mm in size at least. Also, it should be parallel to presser-foot. The instrument has a circular guard ring has a mass of 1000 gr, its external diameter is not bigger than 125 mm and its internal diameter is $d + 40$ mm, where $d$ is the diameter of the presser-foot. For the atmosphere for conditioning specimens, the standard ISO 139 is followed. Selecting specimens is accomplished according to ISO 1957.

To start the test, the presser-foot should be able to move smoothly and the gauge or the base plate should be set to zero. Then the specimen should be placed on the base plate, there is no part of the presser-foot should be found within 20 mm which presents the distance between specimen and the presser-foot. In case the specimens are with pile yarn, the guard ring should be used and the presser-foot should be lowered smoothly on the specimen, then the gauge reading should be recorded after 30 s. Minimum 5 specimens should be tested in case of carpets with yarn pile, and 10 specimens for other types. The thickness of each specimen should be recorded to the nearest 0.1 mm at a pressure of 2,0 kPa, and the mean should be calculated [8].

## 2.2 Commercially Available Instruments for Static Loading and Thickness Measurement

### 2.2.1 WIRA Carpet Static Loading Instrument

The WIRA carpet static loading instrument, Figure 2.5, provides a way to simulate the ability of floorcoverings to recover after applying a load for specific time. This test instrument has a presser-foot with an area of 6.0 $cm^2$ which provides the presser-foot with flexibility of movement in the compressed area. The instrument conducts generally a load of 7.0 $kg/cm^2$ for 24 hours on specimen, this instrument simulates loads caused by furniture. The instrument meets the standards ISO 3416, TS 7578, BS 4939. This device in only used to apply a required amount of static load for necessary time period. The thickness measurement is achieved with a separate device.

**Figure 2.5** WIRA carpet static loading tester [44]

The test device is applicable to all textile floorcoverings of uniform height and construction. In addition, it can be used to other types when the areas of different thickness and construction are separately tested [44].

### 2.2.2 IDM Static Load Tester for Carpet

This test device, Figure 2.6, is applicable to all carpets of uniform thickness and construction.

The test device provides a procedure to apply static load to carpets. The device capable of applying a static load to 15 specimens at the same time. A prolonged heavy static loading treatment is applied by this device and the thickness is measured before loading and after various recovery periods via a separate thickness measurement device.


**Figure 2.6** Static load tester for carpet [45]

This device in only used to apply a required amount of static load for necessary time period. The thickness measurement is achieved with a separate device [45].

### 2.2.3 WIRA Digital Thickness Gauge

The device, shown in Figure 2.7, is suitable for testing in many applications including; carpet thickness, carpet and underlay compression and recovery from compression.

This test device can determine the thickness and recovery from compression. It has the ability to measure the thickness up to 25mm. The device contains a presser-foot, reference plate, guard ring and set of weight to apply pressures of 2, 5, 10, 20, 50, 100, 150, and 200 kPa. The results are displayed on a digital screen.

**Figure 2.7** WIRA digital thickness gauge [46]

The instrument meets ISO and BS standard pressures for testing carpets, underlays, nonwovens and geotextiles ISO 1765:1986 “Determination of thickness of textile floorcoverings”, BS 4051:1987 (1996) “Determination of thickness of textile floorcoverings”, BS 4098:1975 (1996) “Determination of thickness, compression and recovery characteristics of textile floorcoverings”, BS 5808:1991 (1996) “Specification for underlays for textile floorcoverings”, and ISO 1766:1999 (BS) “Textile floorcoverings: Determination of thickness of pile above the substrate” [46].

### 2.2.4 SDL Digital Thickness Gauge

This test device, Figure 2.8, is used to measure thickness of carpet. The weight range of specimen is between 20-2000 g/cm$^2$. The device has a presser-foot with an area of 412mm$^2$, and the range is 0.25 mm × 0.01 mm.

The area where the specimen is placed has a limitation in height. Therefore, this test device cannot be used to test the thickness of thicker materials, such as 3D fabrics.

The instrument is able to determine the thickness of textile floor coverings following standard BS 4051 and determine the compression and recovery characteristics of textile floor coverings according to standard BS 4098. In addition, the instrument has the ability to determine the constructional details of carpets with yarn pile following standard BS 4223 and measure the thickness of machine-made textile floor coverings following standard ISO 1765 [47].


**Figure 2.8** SDL Digital Thickness Gauge [47]

# CHAPTER III

# DEVELOPING A NEW TEST DEVICE

## 3.1 Reasons for Developing a New Test Device

The disadvantages of commercially available test devices are summarized as follows:

- Some of the commercially available test devices are able to provide the required amounts of loads on specimens. However, they do not have a tool to measure the thickness of the tested specimen. That is why an additional tool to measure thickness is needed to perform tests.
- Manual control is used in the available test devices which means that the fault from the side of an operator may occur and the obtained test results may not be reliable.
- Findings of tests are not provided in a digital environment and are not stored.
- There is a limitation in thickness measurement of thicker samples, such as 3D fabrics due to the limitation in the height of the place where the specimen is being placed.

The newly designed test device is superior to the commercially test devices due to the following reasons:

- Static loading procedures for both brief moderate and prolonged heavy tests and thickness measurement of the carpet can be done by a solo test device, thereby the place requirement of the laboratory and the investment cost can be minimized.
- Accurate and precise thickness measurements can be obtained since the tests are implemented automatically without the intervention of an operator for loading and unloading the samples and taking the measurements of thickness. Thereby, the possibility of faults from the operator side can be decreased
- Test data can be stored in a digital environment.
- Thicker textile material, such as 3D fabrics are able to be tested using the new test device.

## 3.2 Design Requirements

Several essential issues were studied and taken into consideration while designing the test device in order to have a reliable test device that is able to provide accurate and precise measurement.

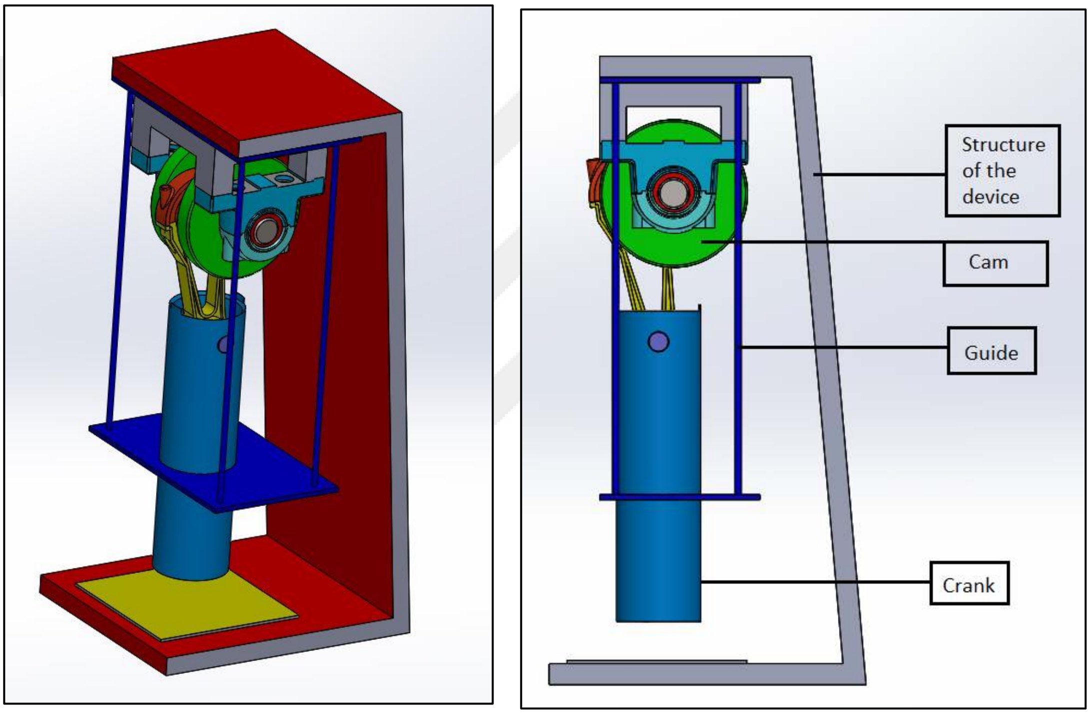
- The device must have a presser foot with an area between 300 $mm^2$ and 1000 $mm^2$.
- The applied pressure must not have high fluctuation among the application duration.
- It must be ensured that the force on the specimen is identical at every part.
- The presser foot must move perpendicularly on the specimen and must run smoothly.
- The component of the test device must be easy to manufacture (less moving components) and not expensive.
- The test device must be able to be controlled automatically.
- The structure of the test device must handle the forces that are going to be applied during static loading tests, such as 220 kPa and 700 kPa.
- The usage of the test device must be easy and does not require skilled operator.
- The components of the test device must not provide annoying sounds while working.
- The test device must be able to calibrate regarding balance before testing due to the importance of performing tests on a flat surface to achieve regular pressure on specimens.
- The findings of the tests should be able to be stored in a digital environment.
- The test device must be able to provide low pressure on specimen such as 2 kPa for thickness measurements and high pressure such as 220 kPa and 700 kPa for the static loading tests.
- 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.

## 3.3 Alternative Designs for A New Test Device

### 3.3.1 Motion System with Crank Mechanism

In this motion system a crank mechanism, given in Figure 3.1.A (3D view) and Figure 3.1.B (side view), is used to convert the circular motion of a motor into linear reciprocating motion. The change in applied forces will be obtained by a servo motor equipped to the system. The required amount of pressure will be obtained through converting the torque of the servo motor, which is controlled through a microcontroller, into a linear force with the means of a crank system. When higher load is needed, the servo motor will rotate with higher torque. A position sensor will be attached to the crank. It will measure the thickness of the specimen. The thickness measurement will be shown on a small screen that is controlled by a microcontroller.

In this system controlling the applied forces is considered difficult since the motion of the crank is continuous and constrained by the rotation of the motor.




**(A)** **(B)**

**Figure 3.1** Motion system with crank mechanism

Another disadvantage of this design is the restriction in using specimens with different thicknesses since the rotation of the crank is steady and can't be changed easily.

### 3.3.2 Motion System with Gearbox

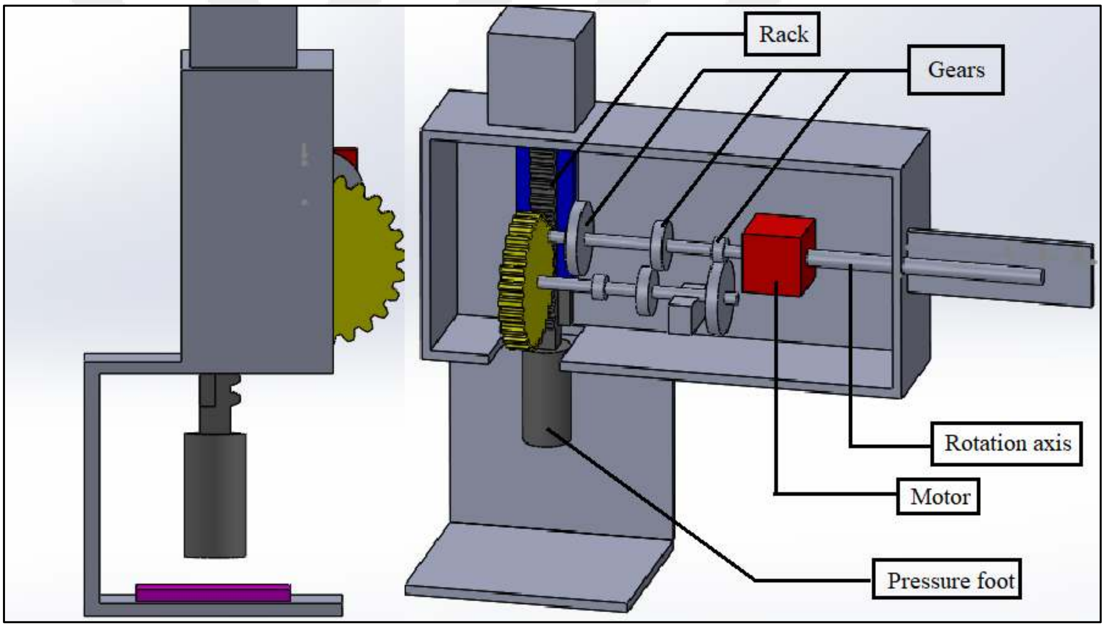
Often the term transmission refers simply to the gearbox that uses gears and gear trains to provide speed and torque conversions from a rotating power source to another device. This system, given in Figure 3.2.A (side view) and Figure 3.2.B (3D view), is able to give three speeds options since three couples of gears exist. A servo motor provides motion to the system. The relationship between the torque and force is given in the equation 3.2 below.

$$T = F \times R \tag{3.2.2}$$

Where, $T$ : torque ($N.m$), $F$ : force ($N$), and $R$ : length of the moment arm (m)

In this mechanism, there are three different options of pressure value can be achieved through changing the contact point between gears as it is explained in the Figure 3.3 below.

In this system it is difficult to change the torque as it is needed, also designing and manufacturing gearbox is expensive. In addition to the fact that the gearbox takes up too much space to obtain high torque values.




**(A)** **(B)**

**Figure 3.2** Motion system with gearbox

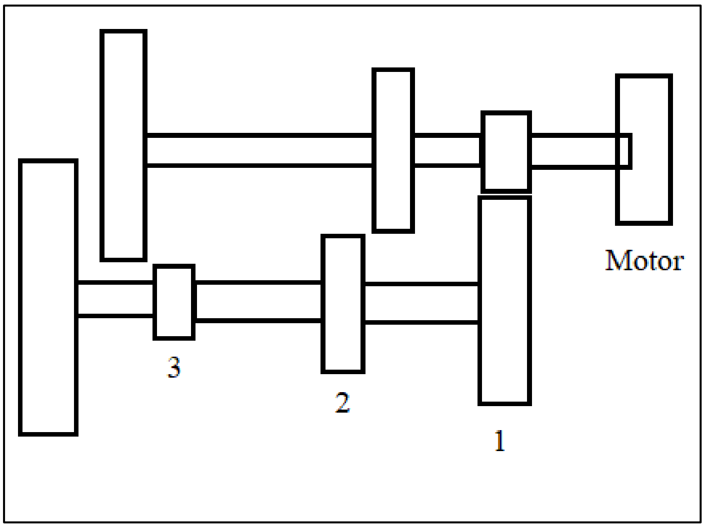



**Figure 3.3** Options of pressure value

### 3.3.3 Motion System with Pneumatic Piston

The motion in this system, given in Figure 3.4, is obtained through a pneumatic system. The initial cost is acceptable. This system manufacturable. The accuracy of the testing process is high because applied forces are controllable through a load-cell mechanism. Applying different forces at specific times is easily possible with this mechanism. The control of the system is considered uncomplicated since the main component of the system is the piston that is taking orders from an Arduino main controller in a computer environment.

The air provided to the circuit through an air compressor. Then the air passes through a regulator which regulates and controls the amount of air that is going to pass into the piston which is attached to the presser foot that provides, eventually, the required pressure. This mechanism is equipped with a solenoid that determines the direction of the movement of the piston. A load cell of the system is used to ensure that the test device is providing the required amount of pressure. The test device is controlled through a microcontroller which sends orders to the components of the test device.

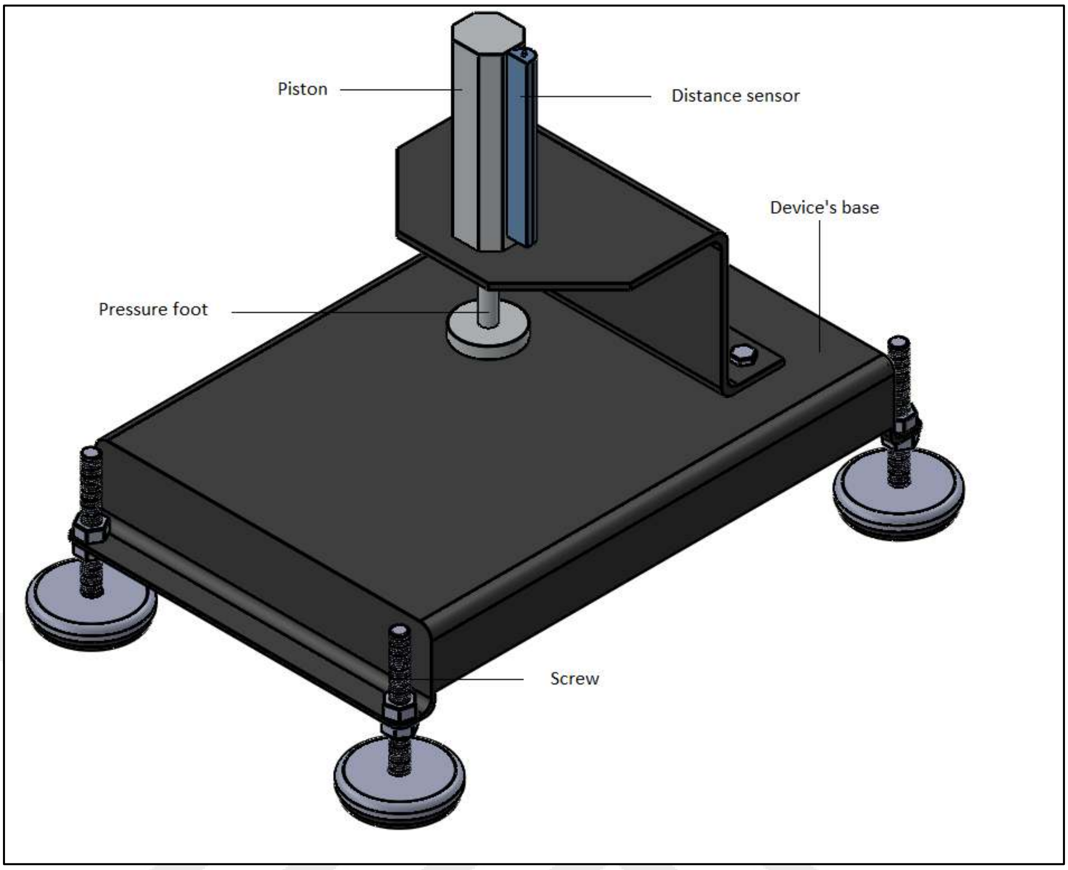



**Figure 3.4** Motion system with pneumatic piston

### 3.3.4 Criteria of Selection Process

The following Table 3.1 represents a comparison between the presented motions systems.

**Table 3.1** Comparison between the motions systems

| | **Crank mechanism** | **Gearbox** | **Pneumatic piston** |
|---|---|---|---|
| **Manufacturability** | | | |
| **Manufacturing cost** | | | |
| **Ability of applying forces accurately** | | | |
| **Operating costs** | | | |
| **Maintenance cost** | | | |

| | | |
|---|---|---|
| Bad | moderate | good |

The Pneumatic piston was selected as a motion system to be equipped to the prototype for the following reasons:

- Accurate loads can be applied because all the loads that are going to be applied are previously tested using a load cell.
- The existence of air regulator ensures applying steady loads during tests.
- Immediate change of the loads can be done easily
- The air circuit that is equipped with air regulator is perfect in meeting changes in loads that may occur during tests.
- Easy set-up of the system when comparing with the other proposed designs.
- The components of the design can easily be manufactured.
- The required components of the design are less when comparing to other designs.
- The control of the components of the air circuit is feasible and easy to be performed automatically using a microcontroller.

# CHAPTER IV

# DESIGNING AND MANUFACTURING OF PROTOTYPE TEST DEVICE

## 4.1 Principle of Operation

Figure 4.1 represents the 3-D isometric view of the prototype and its components. The working principle of the test device is, receiving the instructions from an interface of Arduino. A USB connection between Arduino and the laptop is used to control each component of the prototype.

Regrading calibration, for initializing the test device first, by pressing “calibrate the test device” from the interface of Arduino the presser-foot goes down and up for 100 times in order to warm up the piston then the position sensor should be calibrated by choosing “calibrate the position sensor” from the interface of Arduino. In this stage the presser-foot goes down to identify the zero point and goes up to identify the highest point that the presser-foot can reach. By this way the position sensor builds its scale. Then the tests that can be applied through the test device are shown in the interface as:

“Please choose the test:

1. Thickness measurement.

2. Brief, moderate loading test.

3. Prolonged loading test.”

By choosing the test that we want, the test gets started. After the test is accomplished. The expression “The test is done” is shown in the interface of the Arduino and the interface provides us with the ability of choosing the same test or another test.

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 pressure regulator and the piston presses on the sample through its pressure foot. The pressure foot is made of Aluminum for two reasons; first, reaching light loads such as 2 kPa and second, to benefit from the hardness of Aluminum which is required for applying high loads such as 220 kPa, and 700 kPa.

The piston applies the required loads on the sample. The value of applied load is detected previously using a load cell which is equipped to the test device.

The position sensor, which is attached to the piston, will play an essential role in determining the stroke of the piston continually. With the help of the position sensor, the thickness of the sample will be measured. All the obtained measurements will be stored and displayed in the interface of Arduino software.

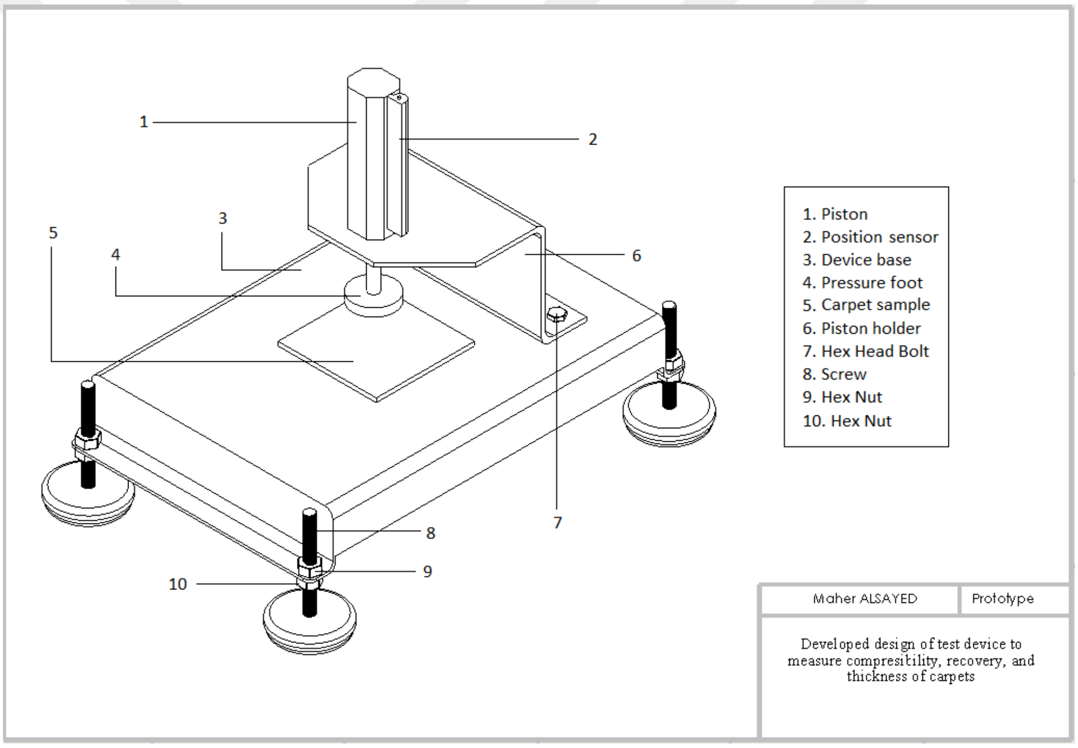



**Figure 4.1** 3-D isometric view of the prototype and its components

The scenarios of the tests that will be conducted according to the required test type is summarized in Figure 4.2.

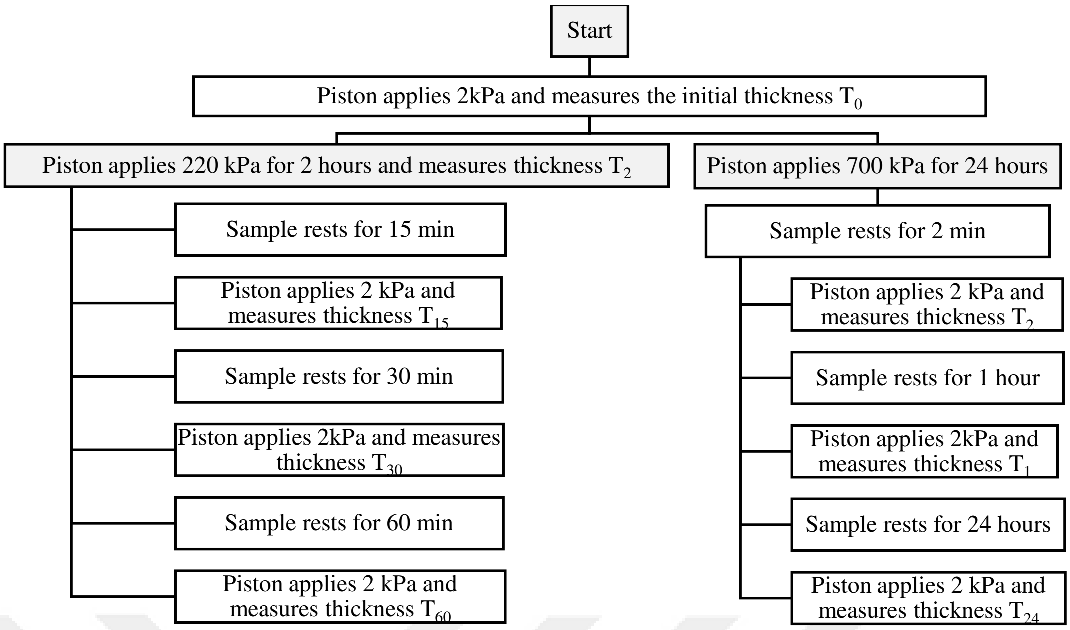



**Figure 4.2** Thickness loss after brief, moderate and prolonged heavy static loading tests

The following diagram, Figure 4.3, represents the control block diagram of the prototype.

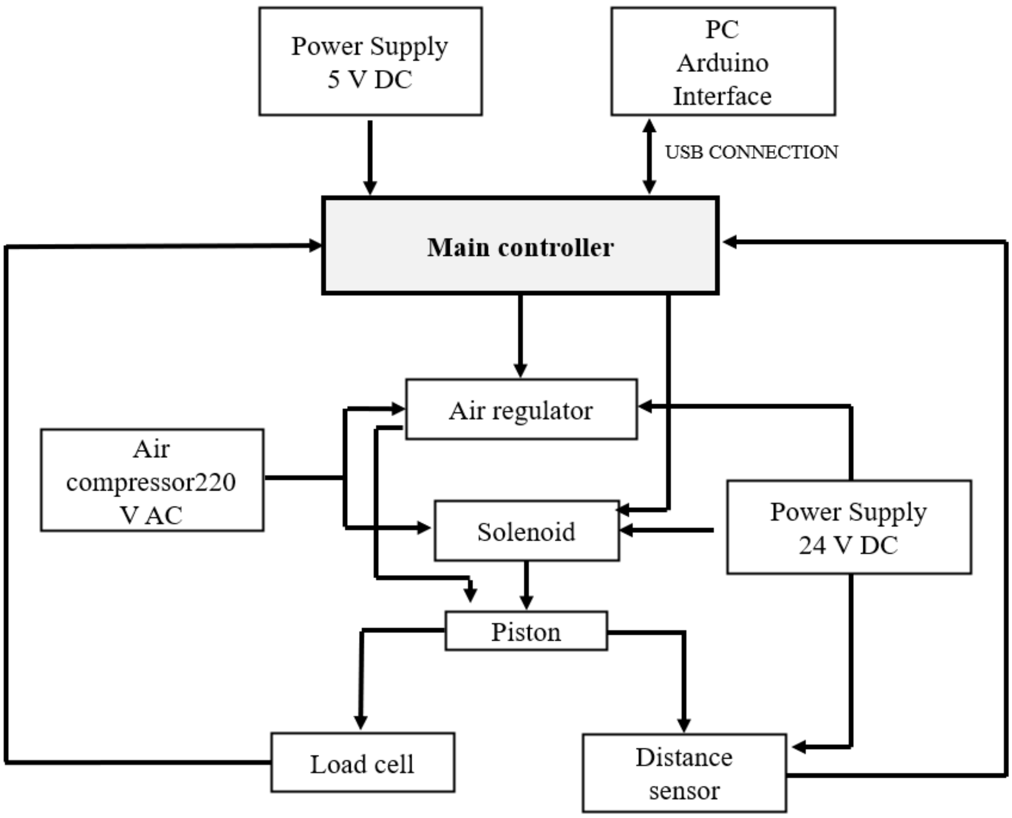



**Figure 4.3** Block diagram of the communication in the testing process.

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

The main controller is responsible for:

- Generating required signals to send commands to the pressure regulator and the solenoid valve.
- Receiving data from the load cell and the position sensor.
- Reading and writing data to the user interface.

As it is explained in Figure 4.3, the main controller sends orders to the pressure regulator and solenoid to control the movement of the piston and the amount of the pressure 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.

Figure 4.4 represents the pneumatic circuit and the movement system of the test device. It can be noticed that the piston moves linearly and perpendicularly on to the device base. The piston has 9 cm stroke and makes this stoke in 1 second. The moving component of the mechanism is the piston. The degree of freedom of the piston in the presented mechanism is 1 since the piston is able to move linearly in one direction (up and down). Figure 4.4 explains the pneumatic circle of the test device and its components. The two-position and three-way 3/2 pneumatic solenoid valve is the responsible component for the determination of movement direction. 3/2 refers to two working positions and three ports in the piston body, namely 1 the inlet port, 2 and 3 are the outlet ports, as it is shown in Figure 4.4 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 so the piston goes down, and vice versa.

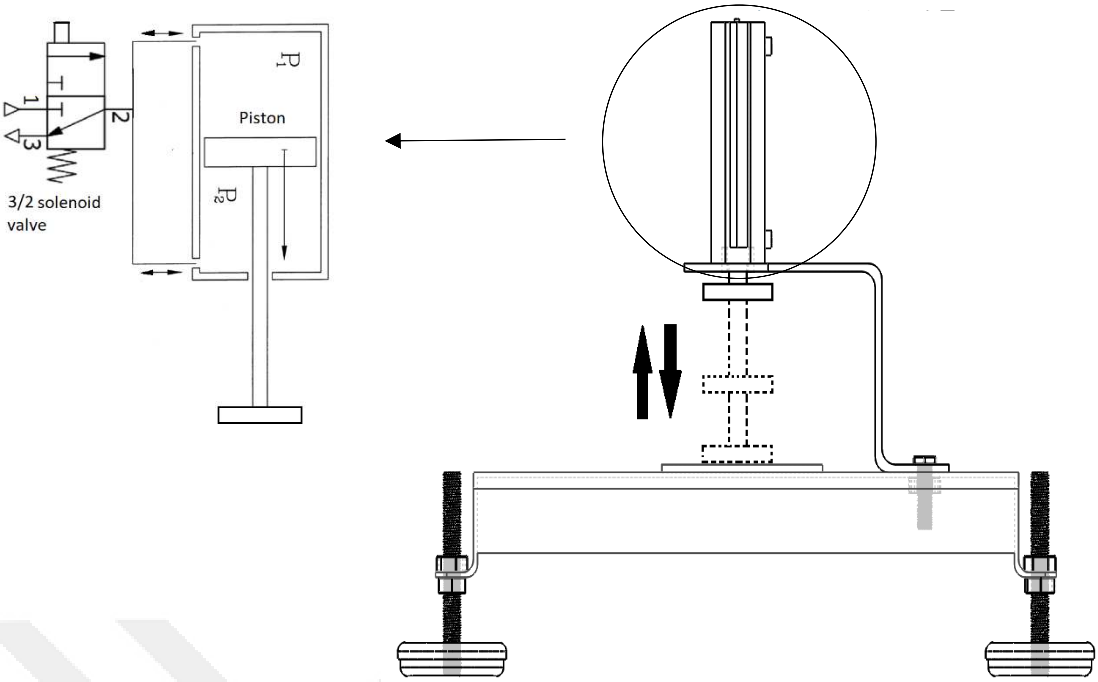
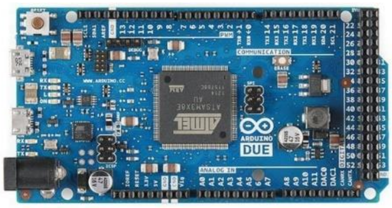


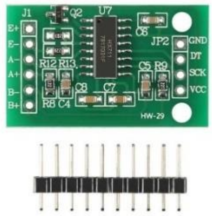

**Figure 4.4** The pneumatic circuit and the movement system of the test device

Components of test device are represented in Table 4.1.

**Table 4.1** Components of the test device

| | Component name | Function | Component photo |
|---|---|---|---|
| 1 | Silent air compressor | Provides the air circuit with air as needed. The specification of the compressor: provision of air pressure up to 8 bar, the volume of the compressor tank is 6 litter, and motor power is 1 hp, 750 W. In addition to being able to work without annoying sound (57 dB). |   |

| | | | |
|---|---|---|---|
| 2 | Pressure regulator | Prevents pressure fluctuation and controls the amount of provided air to the piston. |  |
| 3 | Two-position and three-way 3/2 pneumatic solenoid valve | The responsible component for the determination of movement direction. |  |
| 4 | Arduino UNO | In charge of controlling the whole air circuit, by sending and receiving orders to/from the circuit components. |  |
| 5 | Arduino Due | In charge of controlling the load cell; calibration, sending orders, and showing the value of loads. |  |
| 6 | Load cell | Measures the applied loads before the test. It is able to measure loads up to 100 kg with an accuracy 0.02. |  |

| | | | |
|---|---|---|---|
| 7 | Precision 24-bit analog-to-digital converter (ADC) | Amplifies signals from load cells and reports them to another microcontroller |  |
| 8 | Pressure watch is equipped to the air regulator | Responsible of controlling the amount of pressure that the regulator will receive (unit is bar). |  |

## 4.2 Manufacturing processes

### 4.2.1 Pneumatic Piston

- The main component of the prototype's motion system, shown in Figure 4.5. The piston provides the reciprocating motion of the presser foot.
- The used piston has 9 cm stroke.
- One of the most essential criteria that was taken into consideration while purchasing the piston is the ability to provide low pressure, such as 2 kPa and high pressures, such as 220 kPa and 700 kPa

**Figure 4.5** Pneumatic piston

### 4.2.2 Manufacturing of Presser Foot

While planning to manufacture the prototype, the shape, the dimension, and the weight of the presser-foot was one of the hardest components to be designed and manufactured. First of all, in order to figure out whether the available test devices provide correct results, the dimension of the pressure-foot of the available test devices (SDL and Wira) was measured and loads that the test devices provided were studied as well. The diameter of the pressure foot of the test devices was measured using a manual caliper while the loads that the pressure-foot of that test devices were measured utilizing the load cell of the test device that shows the amount of load in gram using Arduino and in a computer environment. Through using the formula 4.2.1.1, it was found that SDL and Wira test devices provide correct value of pressures on specimens.

Second, to test the applied loads and to ensure that the applied loads are compatible with related standards, the forces applied during the brief, moderate loading test, and prolonged loading test were converted into gram unit to measure the loads using the load cell which recognizes gram as a measurement unit.

$$F = P.A \tag{4.1}$$

Where, *F*: force (*N*), *P*: pressure (*Pa*), and *A*: the area of the presser-foot ($\pi * r^2$)

The first designed and manufactured presser foot has a diameter of 20 mm.

For 2 kPa:

$$F = 2 * 1000 * (\pi * r^2) = 2 * 1000 * \pi * (0.01)^2 = 64\ gr \tag{4.2}$$

For 220 kPa:

$$F = 220 * 1000 * (\pi * r^2) = 220 * 1000 * \pi * (0.01)^2 = 7047\ gr \tag{4.3}$$

For 700 kPa:

$$F = 700 * 1000 * (\pi * r^2) = 700 * 1000 * \pi * (0.01)^2 = 22424\ gr \tag{4.4}$$

The application of 2 kPa and obtaining 64 gram on the specimen through the presser foot was found to be impossible because the lowest force that is sufficient to facilitate the movement of piston onto the specimen and overcome the friction inside the piston is creating approximately 225 gram on specimen which is more than the acceptable value of application for 2 kPa (64 gram). Reaching 2 kPa by using the same presser foot was not possible. The presser foot is made of metal and has a diameter of 20 mm. So, we have three variables that can affect the applied pressures on the specimen which are; the material of the presser foot, the diameter of the presser foot, and the pressure of air from the air regulator.

To figure out the suitable diameter of the presser foot that is appropriate for 2 kPa and 225 gram, the follow formula was used:

$$F = P.A$$

$$P = \frac{F}{A}$$

$$(0.225 * 9.81 * 4)/(\pi * D^2) = 2000$$

$$D = 0.035\,m = 35\,mm$$

In case we use a presser foot that has a diameter of 35 mm and for 2 kPa, the weight on the specimen will be:

$$P = \frac{F}{A}$$

$$2000 = \frac{F * 9.81 * 4}{\pi * (0.035)^2}$$

$$F = 196\,gram$$

According to related standards, the value of pressure is 2 kPa ± 0.2, thereby:

$$F = 196 \pm 19\,gram$$

In order to achieve 2 kPa during the thickness measurement. 5 presser foots were designed and manufactured as it is explained in the Table 4.2 below and given in Figure 4.6:

**Table 4.2** Specification of manufactured presser foots

| | Material | Presser foot diameter (mm) |
|---|---|---|
| 1 | Metal | 20 |
| 2 | Metal | 35 |
| 3 | Aluminum | 35 |
| 4 | Aluminum | 40 |
| 5 | Aluminum | 45 |

The reason behind designing and manufacturing presser foot with a diameter of 40 and 45 and made of Aluminum is to have the ability of applying more than 196 gram (2kPa) on specimen in case we could not apply 196 gram.

The selection criteria of the presser foot were:

- Provision of 2 kPa.
- Ability to sustain for high pressures, such as 220 and 700 kPa.

After testing all the manufactured presser foot, it was found that the presser foot that made of Aluminum and have the diameter of 35 mm is the most appropriate presser foot for the application of 2 kPa and the toleration of high values of pressure while the other presser foots were found to provide more than 2 kPa on specimens.

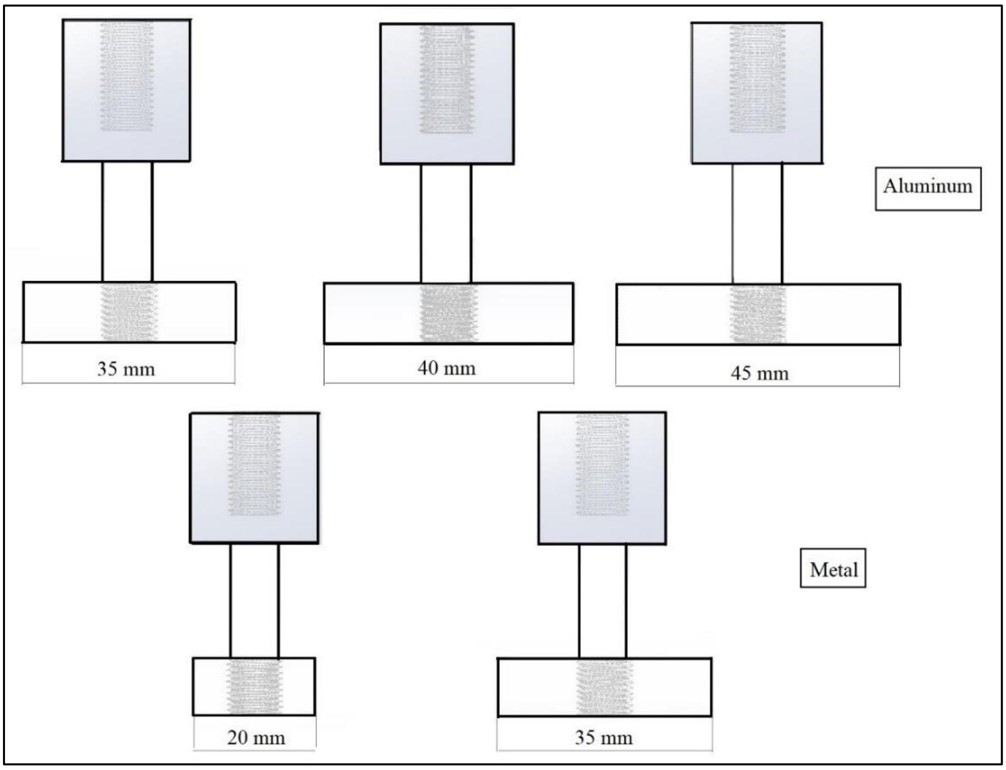



**Figure 4.6** Designs of presser foot

Additionally, in order to apply 2 kPa on the specimen, not only the presser foot was manufactured from Aluminum with a diameter 35 mm but also during the test when the presser foot touches the specimen, the pressure of air of the piston is set to **zero** in order to let the presser foot applies only its weight on specimens. Eventually, the applied pressure on the surface of specimens becomes 2 kPa ± 0.2. The photographic view of the presser foot is shown in Figure 4.7 below.

**Figure 4.7** Photographic view of the designed presser foot

### 4.2.3 Manufacturing of The External Body of The Test Device.

- The external body, shown in Figure 4.8, holds the components of the test device and makes the condition of the experiment balance. The body was made of durable metal to handle the loads that the test device will meet.
- The process manufacturing was accomplished using laser cutting to obtain clean edges.
- 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 × 40.70 cm × 5.00 cm.

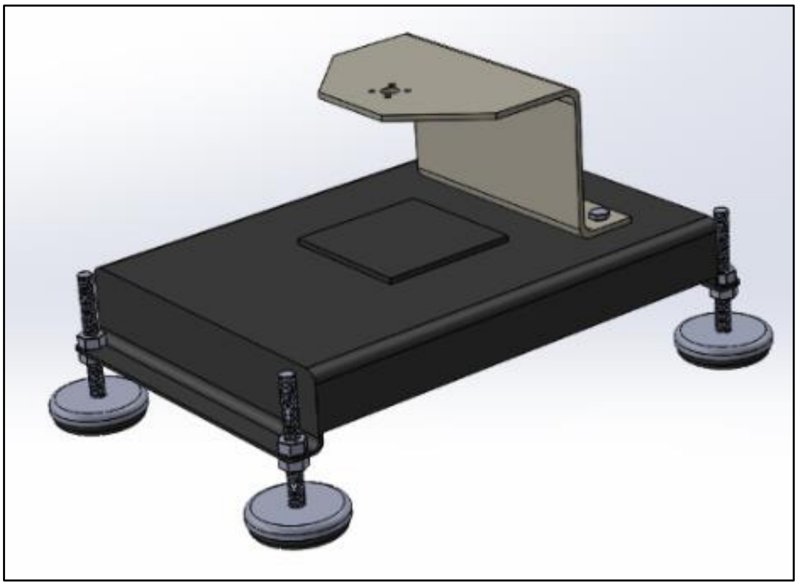


**Figure 4.8** External body of the test device

Figure 4.9 represents the photographic view of the newly designed test device. The external body holds the piston and the load cell. The piston is placed perpendicularly on the base of the external body. The load cell is placed in the front of the test device is a way to facilitate using it to measure the applied pressure through the presser foot. The air regulator in Figure 4.9 is located behind the piston.

The air regulator is shown in Figure 4.10, and the regulator and the used microcontroller (Arduino) are shown in Figure 4.11.


**Figure 4.9** Photographic view of the newly designed test device.


**Figure 4.10** Photographic view of the air regulator

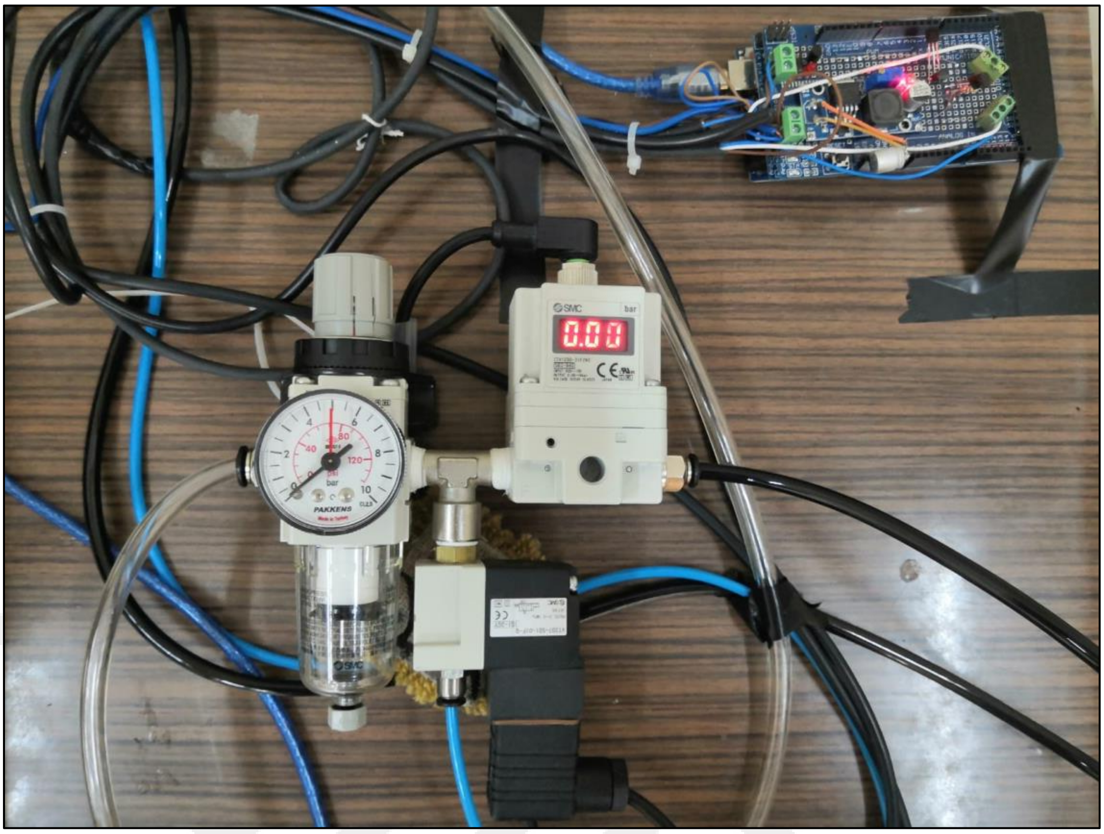



**Figure 4.11** Photographic view of the air regulator with Arduino

# CHAPTER V

# VERIFICATION PROCESS OF THE PROTOTYPE TEST DEVICE

Validation is the confirmation process achieved by obtaining clear evidence that a special purpose of use or an application is fulfilled the conditions according to standard ISO 9000. According to ISO / IEC 17025, it is a confirmation that the requirements for a special purpose of use have been fulfilled the required conditions and an objective evidence is obtained. According to VIM (The International Vocabulary of Metrology), it is defined as “The verification of the sufficiency of specific conditions for special purpose of use”.

The validation of a method is basically a process of confirming that the analytical requirement is defined and that the method is capable of meeting the need. Validation and verification are different concepts. ISO 9000 defines verification as “confirmation that specified conditions are met by providing clear evidence”. It is very similar to the definition of validation. VIM defined verification as “providing clear evidence that an element meets specified requirements”. On the other hand, validation is defined as “verifying that specified requirements are sufficient for an intended use”

A laboratory may adapt a validated procedure, such as a standard published procedure, or the measurement system of a commercial manufacturer for particular use of an application. Methods published by organizations such as ISO or ASTM are already validated. Therefore, there is no need to validate them by laboratories, in either case, the laboratory has completed the basic validation work, yet still needs to confirm its ability to apply the method.

This is the verification procedure that the end user has to assure that the method is applied properly in the laboratory. Verification is also required in case of significant changes, such as relocation the test device or assigning a similar but new test device.

ISO 15189 emphasizes that the procedure that will be used, before doing the routine tests, should be validated independently by the laboratory. In this thesis study, the prototype test device that will be manufactured will be capable of applying the test procedures according to standards published by international standardization organizations. There is no change planned to the applied method. The principle of application of static loading with previously accepted devices will be changed. Therefore, a new method will not be applied by the device which will be designed. So, it is clear that there is no need for validation procedure. However, the verification procedure will be performed. The verification procedure is a procedure that does not contain as many details as the validation procedure but it makes significant determinations [48].

In the designed test device, the applied load amount and time will be measured and tested with control system elements and sensors which will be used. There is no need to verify the amount of applied load. On the other hand, a verification procedure will be required for thickness measurement.

In the verification procedure for the thickness measurement, the "accuracy" criterion will be taken into consideration. The accuracy criterion is determined by identifying "trueness" and "precision".

To calculate trueness, systematic error (bias) is calculated. Systematic error indicates the ability of a measurement method to give true results. In order to calculate the systematic error, a reference value, which is considered to be true, must be known. True value can be determined by:

1. Using certified reference material.
2. Using the reference method, or
3. Using proficiency test.

In this thesis study, the trueness will be determined by using the reference method. In the determination of trueness using the reference method, the true value must be found by inter-laboratory collaboration. In this way, the validated reference method and the method that its trueness will be calculated are studied by the same analyst with the same sample. If the reference method cannot be applied in the laboratory, preferably a sample can be sent to another accredited laboratory. The obtained results are compared with by applying t-test or analysis of variance. In this thesis study, for determination of the trueness by using the reference method, SDL ATLAS carpet thickness measuring device at Gaziantep University, Textile Engineering Laboratory will be used as a reference [49].

First of all, the trueness determination will be made for thickness measurement. In the trueness determination procedure, the same samples will be tested by the same operator, using the designed test device and the available reference SDL ATLAS thickness test device. For this purpose; thickness measurements will be made under 2 kPa load by taking 15 measurements from two different carpet samples. Paired samples t-test will be applied to the data obtained by using SPSS statistical package program. In statistical analysis, 95% confidence interval will be taken into consideration.

Precision is the expression of the closeness of measurement results to each other. It shows the consistency between independent analysis results. 4 factors affect the accuracy measurement:

1. Time (short and long-time interval).
2. Calibration (whether recalibration between measurements on the same equipment is done or not).
3. Operator (same or different operators).
4. Equipment (whether the same or different equipment is used in the measurements)

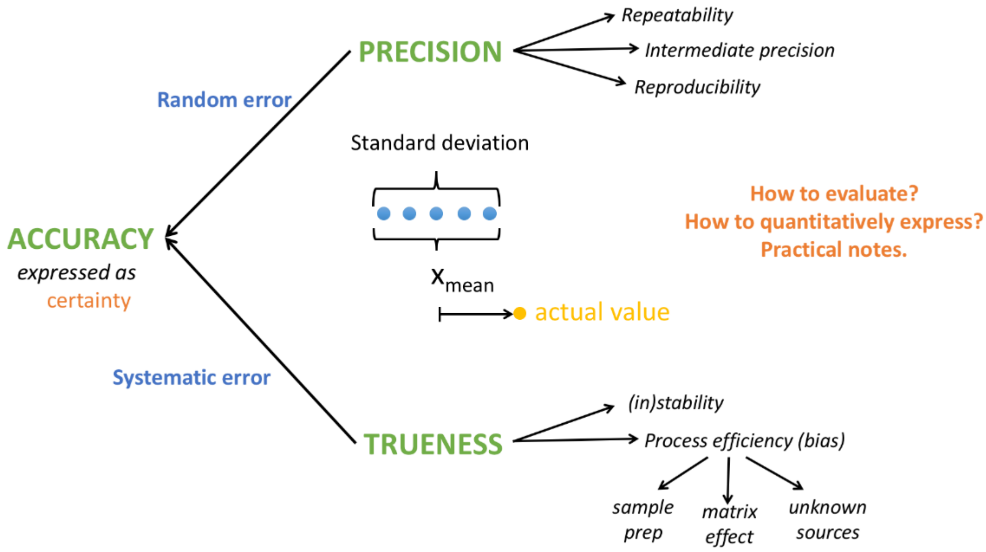



**Figure 5.1** Accuracy, trueness, and precision [50]

The precision varies depending on the variability of these factors. There are two precision measurement as; repeatability and reproducibility as explained in Figure 5.1. Repeatability is the obtained precision under repeatability conditions. Repeatability conditions are defined in ISO 5725-1 as obtaining independent test results by the same equipment, in the same laboratory, and the same analyst over a short-period of time in equivalent samples by using the same method.

In the scope of the study, for the determination of the precision of carpet thickness measurement under repeatability conditions (with the designed test device, from the same carpet sample, by the same operator and within the same day), two different carpet samples will be used. Thickness will be tested by taking 5 measurements from each carpet sample. This process will be repeated 3 times. Analysis of variance will be applied to the data obtained using SPSS statistical package program. If there is no statistically significant difference between the groups as a result of the analysis, it will be decided that repeatability conditions are fulfilled. In statistical analysis, 95% confidence interval will be taken into consideration.

Reproducibility, is the precision obtained under reproducibility conditions. Reproducibility conditions are defined as obtaining independent test results by the same method, by the same samples, in different laboratories, by different equipments and by different analysts over a long period of time. In Eurachem guideline reproducibility is divided into two terms: inter-laboratory reproducibility and intra-laboratory reproducibility. To test accuracy, at least 10 repetitions are provided in the Eurachem guideline, whereas in ISO 5725-3 standard, 15 repetitions are provided. In the scope of this study, 15 measurements will be applied for reproducibility measurements [49]. Within the scope of the study, a reproducibility procedure will be conducted under two conditions as; over a long period of time and by different analysts. For this purpose, two different carpet samples will be used. For the first condition, thickness will be measured by an analyst at 3 different times by taking 15 measurements from each carpet sample. For the second condition, thicknesses will be measured by 3 different analysts by taking 15 measurements from each carpet sample. Analysis of variance (ANOVA test) will be applied to the data obtained by using SPSS statistical package program. If there is no statistically significant difference between the groups as a result of the analysis, it will be decided that reproducibility conditions are fulfilled. In statistical analysis, 95% confidence interval will be taken into consideration.

**Table 5.1** Verification procedure of the prototype test device

| | **Test done by** | **Number of samples** | **Purpose of procedure** |
|---|---|---|---|
| 1 | Prototype + SDL | 2 | Determination of trueness by using reference method |
| 2 | Prototype | 2 | Determination of repeatability |
| 3 | Prototype | 2 | Determination of reproducibility over long time period |
| 4 | Prototype | 2 | Determination of reproducibility by different analysts |

## CHAPTER VI

## RESULTS AND DISCUSSION

### 6.1 Application of Brief Moderate Test

The brief, moderate test was implemented using the newly designed test device. It was observed that the test device is applying the required loads of tests correctly in regards to loads (220 kPa and 2 kPa) and time intervals (applying 220 kPa for 2 h and testing the thickness after 15, 30, and 1 h).

One sample was tested. Figure 6.1 represents the applied 220 kPa load over 1 hour. It was found that the load does not change significantly during the 1 h of loading and the average uploaded load is 7010 gr.

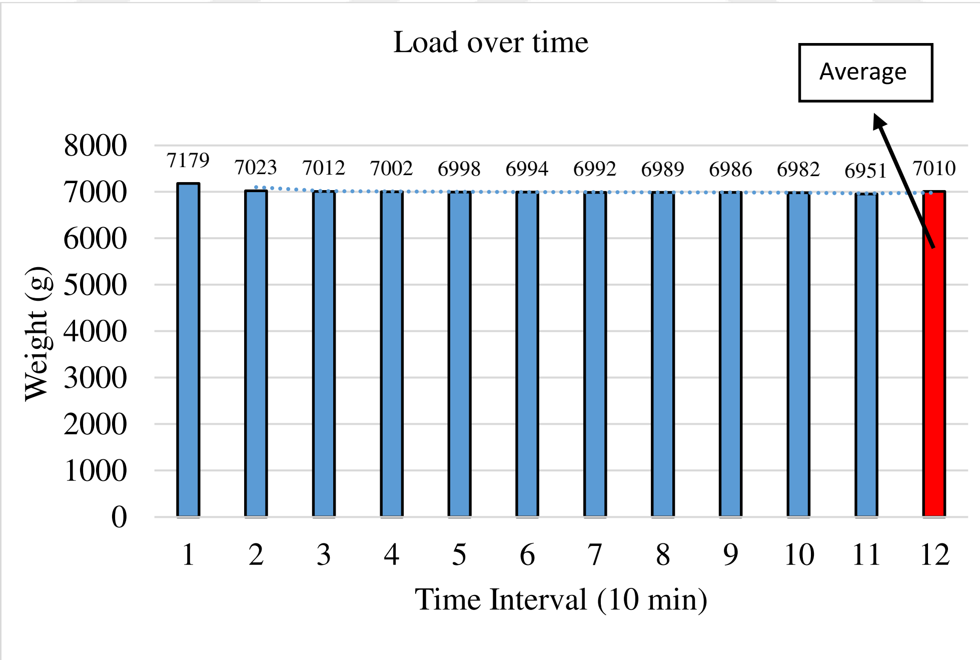



**Figure 6.1** 220 kPa load over 1 hour

The results of the test are provided in the Figure 6.2 below:

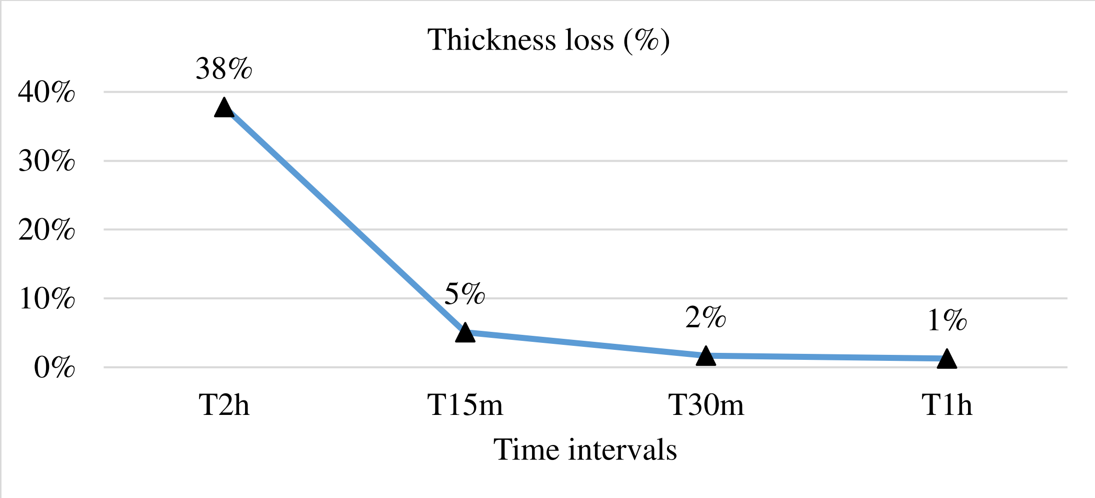



**Figure 6.2** Thickness measurement of the brief moderate loading test

Table 6.1 elaborates on the key findings of the brief, moderate loading test.

**Table 6.1** Findings of brief, moderate loading test

| Abbreviation | Time intervals | Thickness, mm |
|---|---|---|
| $t_0$ | Initial thickness | 14.94 |
| $tL_{2h}$ | Thickness after 2 hours of loading | 9.29 |
| $tR_{15m}$ | Thickness after 15 min of rest | 14.18 |
| $tR_{30m}$ | Thickness after 30 min of rest | 14.69 |
| $tR_{1h}$ | Thickness after 1 hour of rest | 14.75 |

Building on the findings of the brief, moderate test, the thickness loss of the specimen after applying 220 kPa for 2 hours is:

$$t_0 - tL_{2h} = 14.94 - 9.29 = 5.65 \text{ mm} \quad (6.1)$$

While the thickness loss of the specimen of the specimen after a rest period of 15 min:

$$t_0 - tR_{15m} = 14.94 - 14.18 = 0.76 \text{ mm} \quad (6.2)$$

Thickness loss after a rest period of 30 min:

$$t_0 - tR_{30m} = 14.94 - 14.69 = 0.25 \text{ mm} \quad (6.3)$$

Thickness loss after a rest period of 1 hour:

$$t_0 - tR_{1h} = 14.94 - 14.75 = 0.19 \text{ mm} \quad (6.4)$$

In terms of the prolonged loading test, it was found that the load (700 kPa, 22424 gr) is able to be applied using the designed test device.

## 6.2 Results of Verification Procedure

### 6.2.1 Determination of Trueness by Using Reference Method

Two different samples; a cut-pile carpet and a loop-pile carpet were used as samples for the verification procedure. Four type of tests were carried out to prove the accuracy of the newly designed test device. 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 designed test device and the SDL ATLAS (as a reference). The results are presented in Table 6.2.

**Table 6.2** Thickness measurement results of samples for determination of trueness

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

To analyze the obtained data using SPSS, Paired-Sample t-test was conducted. The results of the data analysis of test is shown in Table 6.3. The findings of the data analysis prove that statistically there is no significant difference between the thickness measurements of SDL ATLAS test device and the newly designed test device since Sig. (2. Tailed) = 0.728 > 0.05.

**Table 6.3** The results of Paired-Samples Test

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

### 6.2.2 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 results are shown in Table 6.4 and Table 6.5. Then statistical analyses were done to determine the statistical significance between groups. Thickness measurements and statistical analyses were done for both cut pile and loop pile sample.

**Table 6.4** Thickness measurement results of cut pile sample for determination of repeatability

| Specimen | Measurement 1 | Measurement 2 | Measurement 3 |
|---|---|---|---|
| 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 |

**Table 6.5** Thickness measurement results of loop pile sample for determination of repeatability

| Specimen | Measurement 1 | Measurement 2 | Measurement 3 |
|---|---|---|---|
| 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 test prototype test device, ANOVA test was conducted for thickness measurements of each sample separately.

Cut-pile sample:

The results of statistical analyses of cut-pile sample thickness measurements are provided in Table 6.6 and Table 6.7. The values of cut-pile thickness measurements are normally distributed. The results of the ANOVA test 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 Sig.= 0.823 > 0.05.

**Table 6.6** Results of the normality test for cut pile sample

| **Tests of Normality** | | | | | | |
|---|---|---|---|---|---|---|
| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Cut_pile_sample | 0.180 | 15 | 0.200* | 0.942 | 15 | 0.405 |
| *. This is a lower bound of the true significance. | | | | | | |
| a. Lilliefors Significance Correction | | | | | | |

**Table 6.7** ANOVA results for cut pile sample

| **ANOVA** | | | | | |
|---|---|---|---|---|---|
| Cut_pile_sample | | | | | |
| | Sum of Squares | df | Mean Square | F | Sig. |
| Between Groups | 0.011 | 2 | 0.006 | 0.199 | 0.823 |
| Within Groups | 0.341 | 12 | 0.028 | | |
| Total | 0.353 | 14 | | | |

Loop pile sample:

First the normality test of the thickness measurement was accomplished, shown in Table 6.8. It was found that the values of loop-pile thickness measurements are normally distributed. Then ANOVA test was applied. It was found that, statistically, there is no significant difference between the groups of thickness measurements. The results of ANOVA test are shown in Table 6.9.

**Table 6.8** Results of the normality test for loop pile sample

| Tests of Normality | | | | | | |
|---|---|---|---|---|---|---|
| | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Loop_pile_sample | 0.123 | 15 | 0.200* | 0.960 | 15 | 0.699 |
| *. This is a lower bound of the true significance. | | | | | | |
| a. Lilliefors Significance Correction | | | | | | |

**Table 6.9** ANOVA results for loop pile sample

| ANOVA | | | | | |
|---|---|---|---|---|---|
| Loop_pile_sample | | | | | |
| | Sum of Squares | df | Mean Square | F | Sig. |
| Between Groups | 0.007 | 2 | 0.003 | 0.043 | 0.958 |
| Within Groups | 0.942 | 12 | 0.078 | | |
| Total | 0.948 | 14 | | | |

### 6.2.3 Determination of Reproducibility over Long Time Period

Determination of reproducibility over long time period was done by 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 6.10.

**Table 6.10** Thickness measurements of samples for reproducibility over long time period

| Specimen | Day 1 | | Day 2 | | Day 3 | |
|---|---|---|---|---|---|---|
| | Cut pile | Loop pile | Cut pile | Loop pile | Cut pile | Loop pile |
| 1 | 14.32 | 7.77 | 14.34 | 6.98 | 14.76 | 7.20 |
| 2 | 14.38 | 6.78 | 14.45 | 7.00 | 14.55 | 6.96 |
| 3 | 14.39 | 7.13 | 14.24 | 7.43 | 14.67 | 7.37 |
| 4 | 14.47 | 7.15 | 14.43 | 7.46 | 15.12 | 7.43 |
| 5 | 14.51 | 6.94 | 14.68 | 7.27 | 14.61 | 7.43 |
| 6 | 14.59 | 7.06 | 14.16 | 7.57 | 14.45 | 7.50 |
| 7 | 14.70 | 7.64 | 14.86 | 7.84 | 14.14 | 6.99 |
| 8 | 14.55 | 7.66 | 14.22 | 6.97 | 14.20 | 6.98 |
| 9 | 14.53 | 7.39 | 14.63 | 7.30 | 14.51 | 7.10 |
| 10 | 14.66 | 6.73 | 14.63 | 7.22 | 14.81 | 7.20 |
| 11 | 14.50 | 6.82 | 14.62 | 6.95 | 14.82 | 6.98 |
| 12 | 14.78 | 7.37 | 14.56 | 7.37 | 14.65 | 7.55 |
| 13 | 14.42 | 7.2 | 14.77 | 6.96 | 13.97 | 7.14 |
| 14 | 14.73 | 6.82 | 14.49 | 6.99 | 14.78 | 7.19 |
| 15 | 14.67 | 6.95 | 14.75 | 7.6 | 14.39 | 7.04 |
| **Average** | **14.55** | **7.16** | **14.52** | **7.26** | **14.56** | **7.20** |

Then ANOVA test was carried out to analyze the obtained data.

Cut-pile sample:

The results of statistical analysis of cut-pile carpet thickness measurement are presented in Table 6.11 and Table 6.12. 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 sample over three days of testing as the Sig. = 0.888 > 0.05.

**Table 6.11** Results of the normality test for cut pile sample

| **Tests of Normality** | | | | | | |
|---|---|---|---|---|---|---|
| | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Cut_pile_sample | 0.062 | 45 | 0.200* | 0.984 | 45 | 0.780 |
| *. This is a lower bound of the true significance. | | | | | | |
| a. Lilliefors Significance Correction | | | | | | |

**Table 6.12** ANOVA results for cut pile sample

| ANOVA | | | | | |
|---|---|---|---|---|---|
| Cut_pile_sample | | | | | |
| | Sum of Squares | df | Mean Square | F | Sig. |
| Between Groups | 0.012 | 2 | 0.006 | 0.119 | 0.888 |
| Within Groups | 2.160 | 42 | 0.051 | | |
| Total | 2.172 | 44 | | | |

Loop-pile sample:

The results of data analysis of the loop-pile sample for test 3 are shown in Table 6.13 and Table 6.14. The results seem to be similar to the cut-pile sample's results, where the Sig. value is found to be 0.624 > 0.05.

**Table 6.13** Results of the normality test for loop pile sample

| Tests of Normality | | | | | | |
|---|---|---|---|---|---|---|
| | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Loop_pile_sample | 0.129 | 45 | 0.058 | 0.961 | 45 | 0.133 |
| a. Lilliefors Significance Correction | | | | | | |

**Table 6.14** ANOVA results for loop pile sample

| ANOVA | | | | | |
|---|---|---|---|---|---|
| Loop_pile_sample | | | | | |
| | Sum of Squares | df | Mean Square | F | Sig. |
| Between Groups | 0.075 | 2 | 0.038 | 0.477 | 0.624 |
| Within Groups | 3.321 | 42 | 0.079 | | |
| Total | 3.397 | 44 | | | |

### 6.2.4 Determination of Reproducibility by Different Analysts

In order to determine the reproducibility of the test device by different analysts, thickness measurements of 15 specimens from each sample were done by different analysts. For this aim, three technologists participated in this test. Each technician tested 15 specimens from each sample using the newly designed test device. Table 6.15 and Table 6.16 represent carpet thickness measurement of test 4.

**Table 6.15** Thickness measurement results of cut pile sample for determination of reproducibility by different analyst

| Specimen | Thickness measurements | | |
|---|---|---|---|
| | Technologist 1 | Technologist 2 | Technologist 3 |
| 1 | 14.45 | 14.5 | 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 | 14.4 | 14.34 |
| **Average** | **14.51** | **14.59** | **14.58** |

**Table 6.16** Thickness measurement results of loop pile sample for determination of reproducibility by different analyst

| Specimen | Thickness measurements | | |
|---|---|---|---|
| | Technologist 1 | Technologist 2 | Technologist 3 |
| 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 |
| **Average** | **7.18** | **7.28** | **7.25** |

ANOVA test 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.

Cut-pile sample:

The results of the data analysis are exhibited in Table 6.17 and Table 6.18. The data is distributing normally. As the findings of ANOVA test show, statistically, there is no significant difference between the thickness measurement of the technicians as the Sig. is found to be 0.597 > 0.05.

**Table 6.17** Results of the normality test for cut pile sample

| **Tests of Normality** | | | | | | |
|---|---|---|---|---|---|---|
| | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Cut_pile_sample | 0.097 | 45 | 0.200* | 0.960 | 45 | 0.123 |
| *. This is a lower bound of the true significance. | | | | | | |
| a. Lilliefors Significance Correction | | | | | | |

**Table 6.18** ANOVA results for cut pile sample

| **ANOVA** | | | | | |
|---|---|---|---|---|---|
| Cut_pile_sample | | | | | |
| | Sum of Squares | df | Mean Square | F | Sig. |
| Between Groups | 0.052 | 2 | 0.026 | 0.522 | 0.597 |
| Within Groups | 2.090 | 42 | 0.050 | | |
| Total | 2.142 | 44 | | | |

Loop-pile sample:

The results of the data analysis are shown in Table 6.19 and Table 6.20. The data is distributing normally. As the results of ANOVA test show, statistically, there is no significant difference between the loop-pile sample thickness measurement of the technicians as the Sig. is found to be 0.591 > 0.05.

**Table 6.19** Results of the normality test for loop pile sample

| Tests of Normality | | | | | | |
|---|---|---|---|---|---|---|
| | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Loop_pile_sample | 0.087 | 45 | 0.200* | 0.982 | 45 | 0.707 |
| *. This is a lower bound of the true significance. | | | | | | |
| a. Lilliefors Significance Correction | | | | | | |

**Table 6.20** ANOVA results for loop pile sample

| ANOVA | | | | | |
|---|---|---|---|---|---|
| Loop_pile_sample | | | | | |
| | Sum of Squares | df | Mean Square | F | Sig. |
| Between Groups | .078 | 2 | .039 | .533 | .591 |
| Within Groups | 3.077 | 42 | .073 | | |
| Total | 3.155 | 44 | | | |

# CHAPTER VII

# CONCLUSION

## 7.1 Discussion and Conclusion

The purpose of this study is designing and manufacturing a multifunctional and innovative test device that has the ability of measurement of thickness determining the compressibility and resilience performance of carpets. There are two types of tests to determine the compressibility and resilience performance of carpets namely; the measurement of thickness loss after prolonged heavy static loading and thickness loss after brief moderate static loading.

Secondly, alternative motion systems were compared, and pneumatic piston was selected as the most appropriate system considering the factors which are manufacturability, manufacturing cost, ability of applying forces accurately, operating costs, and maintenance cost.

After design, the prototype of new test device was manufactured. The new test device has the components having different functional which are silent air compressor providing the circuit with air as needed, pressure regulator preventing pressure fluctuation and controlling the amount of air, two-position and three-way 3/2 pneumatic solenoid valve for the determination of movement direction, Arduino UNO controlling the whole air circuit, Arduino Due controlling the load cell, load cell measuring the applied loads, precision 24-bit analog-to-digital converter (ADC) amplifying and reporting signals, and pressure watch controlling the amount of pressure. All the components of the test device work automatically through receiving orders from the main controller (Arduino).

The code of the main controller was written and tested. The software of Arduino through its designed interface ensures the movement of the components and enable the end-user to use the test device and apply loads. Basically, the code allows the end-user conduct test.

A verification process was carried out to know if the test device able accurately to measure the thickness of samples and to understand the accuracy of obtained results. In the precision measurement, repeatability and reproducibility were applied. For repeatability, thickness of the carpet samples was measured under repeatability conditions (with the designed test device, from the same carpet sample, by the same operator and within the same day) 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 an analyst at different times.

By using the SPSS software, the ANOVA test was conducted. 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 and which mean that the newly designed test device meets the reproducibility conditions. The statistical results revealed the new test device has repeatability and reproducibility conditions.

As a conclusion the newly designed test device provides true and precise thickness measurements and is able to apply all the required loads for thickness measurements 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 used.

### 7.2 Recommendation for Future Work

Sometimes when applying 2 kPa on the sample as a part of the tests of carpet for measuring the thickness of the carpet, the presser foot cannot be able to smoothly go down and apply the required load since the friction forces inside the piston hinder the presser-foot movement. In order to overcome this problem, in the calibration process, the presser-foot receives an order to go up and down for 100 times thereby the piston gets worm up. However, in some cases, the presser foot does not go down for one or two times. In order to ensure the smooth movement of the presser-foot, it is highly recommended to add a feedback mechanism under the place of the specimen. This feedback mechanism is equipped with a load cell. The purpose of that is controlling the movement of the presser-foot and providing the presser-foot with the required amount of air as it is required which will ensure the smoothy movement of the presser-foot.

The interface of Arduino was used in this research to show the tests, their results and the period of test implementation and yet it is advisable to have a separate interface using MATLAB to show the test, result, the period of the test since it much easier to deal with and can provide some other features that the interface of Arduino cannot provide except if code of Arduino is changed.

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

## REFERENCES


[1] Gupta, S. K., Goswami, K. K. (2018). Floor Covering Wear Performance. The Textile Institute Book Series, Second Edition, *Elsevier Ltd*, 443-466.

[2] Dayiary, M., Najar, S. S., Shamsi, M. (2009). A New Theoretical Approach to Cut-Pile Floor Covering Compression based on Elastic-Stored Bending Energy, *J. Text. Inst.* **100 (8)**, 688-694.

[3] Carnaby, G. A. Wood, E. J. (1989). The Physics of Floor Coverings*, The Journal of The Textile Institute*, 71-90.

[4] British standard, (1975). Determination of Thickness, Compression, and Recovery Characteristics of Textile Floor, C: BS 4098:1975.

[5] British standard, (1987). Method for Determination of Thickness Loss of Carpets after Prolonged Heavy Static Loading, BS 4939:1987.

[6] American Society for Testing and Materials (ASTM), (2017). Standard Test Method for Measuring Recovery Properties of Floor Coverings after Static Loading, ASTM F970.

[7] Turkish standard, (1991). Carpets-Determination of Thickness Loss After Brief, Moderate Static Loading, TS 3378.

[8] British standard, (1987). Method for Determination of Thickness of Carpets, BS 4051.

[9] WIRA Instrumentation, WIRA Floor Covering Static Loading Tester, http://www.wira.com/media/other/37656/WiraStaticLoading.pdf, 01.05.2020.

[10] WIRA Instrumentation, WIRA Digital Thickness Gauge Floor Coverings, http://www.wira.com/media/other/37656/WiraDigitalThickness.pdf, 01.05.2020.

[11] IDM instrument, Static Load Tester for Carpet. http://www.idminstruments-.com.au/sites/default/files/S0011%20-%20static%20load%20tester%20for%-20carpet_0.pdf, 01.05.2020.

[12] WIRA Instrumentation, WIRA Dynamic Load Machine. http://www.wira.com/media/other/37656/WiraDynamicLoading.pdf, 01.05.2020.

[13] Celik, N., Koc, E. (2010). Study on the Thickness Loss of Wilton-Type Carpets under Dynamic Loading. *Fibres and Textiles in Eastern Europe*. **18(1)**, 54-59.

[14] Kucuk, M., Korkmaz, Y. (2016). Sound Absorption Properties of Acrylic Carpets. *The Journal of The Textile Institute*. 1-8.

[15] Javidpanah, M., Shaikhzadeh Najar, S., Dayiary, M. (2014). Study on Thickness Loss of Cut-pile Carpet Produced with Heat Process-modified Polyester Pile Yarn. Part I: Static Loading, *The Journal of The Textile Institute*. **105(12)**, 1265-1271.

[16] M. Javidpanah, Shaikhzadeh Najar, S., Dayiary M. (2015). Study on Thickness Loss of Cut-Pile Carpet Produced with Heat Process Modified Polyester Pile Yarn. Part II: Dynamic Loading, *The Journal of The Textile Institute*. **106(3)**, 236-241.

[17] Korkmaz, Y., Dalcı Kocer, S. (2010). Resilience Behaviors of Woven Acrylic Carpets under Short- and Long-Term Static Loading, *The Journal of The Textile Institute*. **101(3)**, 236-241.

[18] Celik, N., Koc, E. (2007). An Experimental Study on Thickness Loss of Wilton Type Carpets Produced with Different Pile Materials after Prolonged Heavy Static Loading. Part 2: Energy Absorption and Hysteresis Effect. *Fibres and Textiles in Eastern Europe*. **15**, 87-92.

[19] Dalcı KOCER, S., Korkmaz, Y. (2010). Evaluating Effects of Polypropylene Carpet Production Parameters on Carpet Performance, Electronic Journal *of Textile Technologies*. **4(1)**, 48-58.

[20] Çelik, H. İ. (2017). Effects of Fiber Linear Density on Acrylic Carpet Performance. *Journal of Engineered Fibers and Fabrics*. **12(1)**, 1-11.

[21] Erdoğan Ü. H. (2012). Effect of Pile Fiber Cross Section Shape on Compression Properties of Polypropylene Carpets, *The Journal of The Textile Institute*. **103(12)**, 1369-1375

[22] Çelik, N., Kaynak, H. K., Değirmenci, Z. (2009). Performance Properties of Wilton-Type Carpets with Relief Texture Effect Produced Using Shrinkable, High-Bulk and Relaxed Acrylic Pile Yarns. *AATCC Review*. 43-47.

[23] Özdil, N., Bozdoğan, F., Kayseri, G.Ö., Mengüç, G.S. (2012). Compressibility and Thickness Recovery Characteristics of Carpets. *Tekstil ve Konfeksiyon.* **22(3)**, 203-211.

[24] Dayiary, M., Shaikhzadeh Najar, S., Shamsi, M. (2010). An Experimental Verification of Cut-Pile Carpet Compression Behavior, *The Journal of The Textile Institute*. **101(6)**, 488-494.

[25] Mirjalili, S. A., Sharzehee, M. (2005). An Investigation on The Effect of Static and Dynamic Loading on The Physical Characteristics of Handmade Persian Carpets: Part I – The Effect of Static Loading, *The Journal of The Textile Institute*. **96(5)**, 287-293.

[26] Moghassem, A.R., Gharehaghaji, A.A., Shaikhzadeh Najar, S. (2012). Analysis of Two Soft Computing Modeling Methodologies for Predicting Thickness Loss of Persian Hand-Knotted Carpets. *Fibers Polym*. 675-683.

[27] Vuruşkan, D. (2017). Carpet Fiber Mobility Due to Traffic Wear. *Industria Textila*. **68(3)**, 209-212.

[28] Watson, S. A., Warnock, M. M. (2003). Comparative Analysis between Recycled and Newly Manufactured Carpets. *Family and Consumer Sciences Research Journal*. **31(4)**, 425-441.

[29] Babaarslan, O., Sarioglu, E., Sıdıka Ziba, O. (2017). Compressibility and Resiliency Properties of Wilton Type Woven Carpets Produced with Different

Fiber Blend Ratio, *IOP Conference Series: Materials Science and Engineering*. **254(8)**, 1-6.

[30] Radhakrishnaiah, P. (2005). Comparison of The Performance Properties of Carpets Containing Nylon 6 and Nylon 66 Face Yarns. *Textile Research Journal.* **75(2)**, 157–164.

[31] Vuruşkan, D., Sarıoğlu, E., Çelik, H.İ., Kaynak, H.K. (2017). Compression Properties of Woven Carpet Performance under Dynamic Loading. *Periodicals of Engineering and Natural Sciences (PEN)*. **5**, 279-283.

[32] Hearle, J. W. S., Liu, H. Tandon, S. K., Wood, E. J. (2005). Computational Model of Wool Carpet Wear, *The Journal of The Textile Institute*. **96(3)**, 137-142.

[33] Çelik İ. Ç., Bozoğlan Ö. (2019). An Innovative Solution Approach for Carpet Pile Pull out Problem, *European Journal of Engineering and Applied Sciences*. **3(2)**, 30-34.

[34] Mecit, D., Roye, A. (2009). Investigation of a Testing Method for Compression Behavior of Spacer Fabrics Designed for Concrete Applications, *Textile Research Journal.* **79(10)**, 867-875.

[35] Fujimoto, T., Sunderland, M., Tandon, S., Asano, C., Asano, A., Murata, C., Fukuyama, H. (2008). Measurement of Surface Property Using a Special Sensor Developed of Pile Materials, *Indian Journal of Fibre & Textile Research*. **33**, 253-257.

[36] Yi, L., Yao, B. (2011). Virtual Instrument Based Measurement System for Handle Properties Evaluation of Textile Materials, *Third International Conference on Measuring Technology and Mechatronics Automation, IEEE, Shanghai, China.* **3**, 1120-1223.

[37] Liao, X., Li, Y., Hu, J. et al. (2014). A Simultaneous Measurement Method to Characterize Touch Properties of Textile Materials. *Fibers Polym.* **15**. 1548-1559.

[38] Orr, M., Stowe, D., Thoe, S, Northup, K., Torok, M., ODell, A., Summers, J., Blouin, V., Joseph, P. (2013). Design of a Scaled Off-Vehicle Wheel Testing Device for Textile Tread Wear, *Conference: SAE World Congress, SAE Technical Paper. Detroit, Michigan, United States*.

[39] Sengupta, S., Debnath, S., and Sengupta, A. (2016). Fabric Bending Behavior Testing Instrument for Technical Textiles, *measurement*. **87**, 205-215.

[40] Gupta, S. K., Goswami, K. K. (2017). Carpet Wear Performance, *Second Edition. Elsevier Ltd.*

[41] Dayiary, M., Najar, S. S., Shamsi, M. (2009). A New Theoretical Approach to Cut-Pile Carpet Compression based on Elastic-Stored Bending Energy, *J. Text. Inst.* **100(8)**, 688-694.

[42] Carnaby, G. A., Wood, E. J. (1989). The Physics of Carpets, *The Journal of The Textile Institute*. **80(1)**, 71-90.

[43] Turkish standard (TS), (1991). Carpets-Determination of Thickness Loss After Brief, Moderate Static Loading, TS 3378.

[44] SDL America, K097b Drum Testing Device. http://www.wira.com/media-/other/37656/WiraStaticLoading.pdf. 20.06.2020.

[45] IDM instrument, Static Load Tester for Carpet. http://www.idminstruments.-com.au/products/static-load-tester-carpet. 20.06.2020.

[46] WIRA instrumentation, WIRA Digital Thickness Gauge. http://www.wira-.com/media/other/37656/WiraDigitalThickness.pdf. 20.06.2020.

[47] SDL ATLAS, Digital Thickness Gauge. https://sdlatlas.com/products/digital-thickness-gauge. 20.06.2020.

[48] Magnusson, B. Örnemark, U. (2018). Eurachem Guide: The Fitness for Purpose of Analytical Methods – A Laboratory Guide to Method Validation and Related Topics. 1-62.

[49] Yılmaz. A. (2010). Turklab Kimyasal Analizlerde Metot Validasyonu Ve Verifikasyonu.

[50] Kuttappa. S., Precision, Trueness and Accuracy. https://medium.com-/@shoury01/precision-trueness-and-accuracy-d4f391160e3b, 20.06.2020.