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Research Article

Behavior of Elastic Therapeutic Tapes under Dynamic and Static Conditions

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The aim of this paper is to determine the relaxation behavior of the therapeutic tape under different thermomechanical conditions over different time spans and to analyze the physical and mechanical properties of selected kinesiology tapes. The relaxation test was conducted under a static condition with two extended levels (25% and 50%) for one hour and a dynamic condition for 300 cycles with different loading-unloading values, strain rates, and temperatures. For both static and dynamic conditions, at a lower strain rate and higher load and temperature, the therapeutic tapes showed higher loss of internal stress and faster losses of efficiency. Under all selected conditions, the tape's stress has decreased rapidly.

1. Introduction

Elastic therapeutic tape (ET), also known as Kinesio tape, was developed by Japanese Chiropractor Dr. Kenzo Kase in the 1970s with the intention to alleviate pain [1]. It is an elastic adhesive tape for healing in soft tissues [2] and is widely used for various clinical treatments such as the provision of structural support, reducing muscle fatigue, muscle facilitation, reducing edema, and improvement of lymphatic drainage and blood flow [3]. In general, elastic therapeutic tapes are made of a combination of cotton with polyurethane synthetic fibre coated with hypoallergenic thermos active acrylic acting as an adhesive. The crucial therapeutic factor is the transfer of tension by the tape to the skin, nerves, and circulatory system of the human body to solve the problem as shown in Figure 1. During clinical treatment, before taping to the human body, it needs to stretch to some levels for providing appropriate tension, but the level of stretch depends on the problem to fix [4]. For instance, lymphatic and fascial problem tape recommend 25–50% and 0–15% stretch level, respectively. For ligament and tendon problem, 50–75% is recommended. Generally, the tape can be stretched longitudinally 120–140% from its original length.

The previous study on the Kinesio taping method is devoted to examining its therapeutic effects, or its effect on clinical treatment like athletic performance, lymphatic drainage, healing, and blood flow performance [5–7]. From a methodological viewpoint, these studies are mostly enclosed as randomized clinical trials with an experimental and control group of propends. However, these and other previous studies have a limitation to relate the performance of kinesiology tape on the musculoskeletal system from a fabric properties point of view. To understand the performance in a complete sense, incorporating kinesiology tape's stress field over time on the skin surface would be helpful.

Several studies [8, 9] made a numerical analysis on the impact of loading on the adhesive joint. Their result showed that sensitive materials are largely affected by temperature, static load, and dynamic load. At the same time, other research such as [10, 11] developed correlation between dynamic and static fracture toughness of polyurethane rigid foams. From these studies, it can be understood that adhesive coated sensitive materials such as kinesiology tapes' performance and their service life should be evaluated in a detailed manner by taking several factors into account.

Evaluation, however, requires knowing structural, physical, and mechanical properties, as well as time

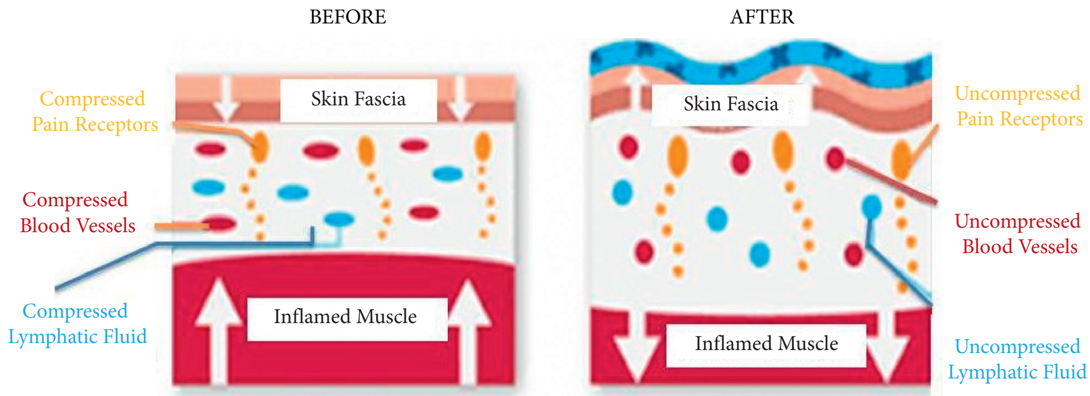


FIGURE 1: Injured area before and after applying Kinesio tape.

dependence of therapeutic tape performance under different conditions. Only a few studies such as [12–14] have selected three different colored kinesiology tapes and described their thermophysiological comfort characteristics (geometrical and mechanical). The kinesiology tapes were made of cotton based woven fabrics, have similar properties to human skin, and are more comfortable to use; they also described that all the tapes they used for their study could transfer heat and moisture from the skin but they all had different mechanical behaviors. The authors have suggested that there is a need to do much research in terms of holding performance of the tapes under different conditions. Producers often promote various comfort properties of kinesiology tapes such as low mass per unit area, elasticity, breathability, and high strength. However, the time-dependent stress relaxation or the change of dimension of the tape under various temperature regimes were overlooked. Stress relaxation is a gradual drop of stress or decreasing holding performance of tapes with time at constant strain. As a result, knowing this drop over time helps in the time required to replace the tape for further compression treatments. Some important variables under dynamic and static conditions should be considered like temperature (°C), load (gm), the percentage of extension, and strain rate (mm/min) which could influence the holding capacity of therapeutic tape over time. The aim of this paper is to study the stress relaxation behavior of tapes under different extensions and temperatures and then assess the dynamic and static response of the stress field developed by tapes under varying cyclic loading and unloading conditions.

2. Materials and Methods

2.1. Materials. Commercially available kinesiology tapes with different brands mentioned in Table 1 are used for the study. All the tapes were new and within the validity period as indicated by their manufacturers. The tapes were packed in 5 m long rolls and 5 cm width and 16.5 ft length. Toluene is used for the removal of adhesive from the back surface of tapes for further physical characterization.

TABLE 1: The different Kinesio brands used for the experiment.

Product name	Tape code
Premium Kinesiology 3NS Tex®	KT1
KinesioTex® gold	KT2
Classic Kinesio Tape	KT3
Mueller Kinesiology Tape	KT4

2.2. Methodology

2.2.1. Methods of Physical Characterization. To examine the physical property of samples, firstly, the sample was immersed in toluene for 24 hours to remove adhesive and evaluate mass per unit area (GSM) and thickness of woven tapes and at the same time material composition of yarns, and percentage of each yarn in the fabric was analyzed, as shown in Figure 2. Then, the residuals of undissolved adhesive were removed mechanically under running water.

Subsequently, the sample was dried and conditioned to a standard temperature and moisture content. The small sample from each tape was cut and deconstructed to get warp and weft yarns. At the yarn stage, warp and weft yarns were studied separately with respect to their fineness and material composition. To determine the linear density of warp and weft yarn, 10 yarns from each sample were pulled out and the length (m) and mass (gm) were measured. Further, tex which is denoting linear density (based on the measured weight and length of yarn, weight per length) was calculated. Mass of yarn was directly determined by VIBRA weight balance (the maximum and minimum caring of this instrument are 620 gm and 0.001 gm, respectively). Thickness and mass per unit area (GSM) with and without adhesive were tested at the fabric stage.

2.2.2. Methods of Mechanical Characterization. The kinesiology tape is characterized by its mechanical properties. The tensile test is taken under standard testing conditions (65% RH (relative humidity) and 27°C temperature). Each tape was cut in 'I' shape in 20 cm × 5 cm according to ASTM

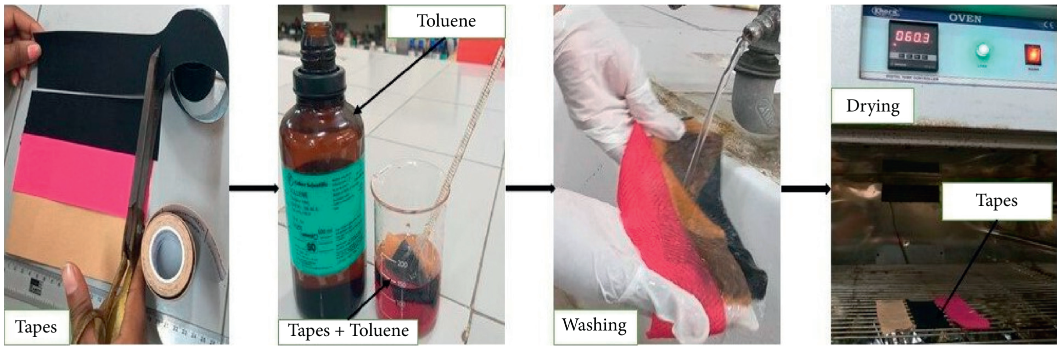


Figure 2: Process of adhesive removal from each tape.

D5034 standard. Then, the tape was mounted between two jaws (upper movable jaw and lower fixed jaw) and covered by paper. The paper was then removed only from gauge length (7.5 cm) after mounting the sample as shown in Figure 3. According to the standard of fabric tensile test, the minimum speed for testing of fabric is 75 mm/min while the maximum speed is 500 mm/min and the failure (break) of samples would be in 20 ± 3 seconds for tensile test. Furthermore, if the speed is lower than the range, the failure of the sample will be late. if it is higher, the sample may break very quickly which affects the final result. For this study, the tensile test ran till the tape gradually pulled to failure (break) at a speed of 300 mm/min.

Finally, the test results are recorded: force (N) with the extension (mm) from which the maximum extension at the break and maximum breaking load has been determined directly. As long as it is a narrow fabric, only longitudinal (warp) direction is considered to determine the mechanical properties of kinesiology tapes. Ten samples from each brand were examined.

2.2.3. Methods of the Stress Relaxation Test. Stress relaxation tests were performed under two different conditions: (i) static condition and (ii) dynamic condition. For the test, four important factors, namely, the strain rate (mm/min), load (gm), extension (%), and temperature (°C), were chosen to analyze their impact on the holding performance of the therapeutic tapes. The entire tests were performed only in the longitudinal or warp directions:

(i) Static relaxation test: the purpose of the static test is to determine how much the tape is deformed statically at the given time and to understand the effect of extension level on the stress profile generated by the therapeutic tape, at room temperature. The test was performed using ASTM D 2256 standard on Instron Universal Tester. The Tester has two different channels: channel one is used to examine the different properties of fabrics with the maximum load cell of 50 N and the second channel is mostly used to examine different properties of different yarns with at maximum load cell of 5 N. The maximum gauge length of the channel is 10 cm and the minimum gauge length is 5 cm. For this study, we used channel one because our sample is fabric.

The following steps are used to investigate the stress relaxation under static conditions [6]: the tape was cut $20\,\text{cm} \times 5\,\text{cm}$ ($20\,\text{cm} \times 5\,\text{cm}$) in ‘I’ shape and mounted between the jaws (upper movable jaw and lower fixed jaw with covered paper) as shown in Figure 4. Then, the paper was removed from the gauge length spot [7]. The sample was stretched up to 25% and 50% from the original length at a strain rate of 300 mm/min at room temperature and then retained for a relaxing period of 1 hr.

Ten samples were examined for each brand. The test results recorded the load (N) versus time (s). Thereafter, the average of the maximum loads (N), the time of total relaxation (s), and the load of total relaxation (N) have been determined.

(ii) Dynamic relaxation test: dynamic relaxation test was examined by varying load, strain rate (speed), and temperature of the tensile testing machine. The testing machine can extend to a maximum of 400 mm/min and a minimum of 25 mm/min.

The same techniques as the static test are followed to determine the sample size and mount the sample on the machine.

(1) Load Variation. For analysis of the effects of load variation on the stress relaxation behavior of therapeutic tape, it is started by choosing the minimum and maximum load, which has been taken from the static test results so that the peak (maximum) loads of 25% and 50% have extensions of 150 gm and 400 gm, respectively. Although two minimum loads have been selected for each extension, for 25% extension 50 gm and 100 gm and for 50% extension 200 gm and 300 gm, all the tests are complemented at two different strain rates (speed) which is 70 mm/min and 100 mm/min under different temperatures. The result was recorded after 300 cycles.

(2) Strain Rate or Speed of Tape Movement Variation. The test indicates a change in strain or deformation of the tape with respect to time. So, for the test, two strain rates have

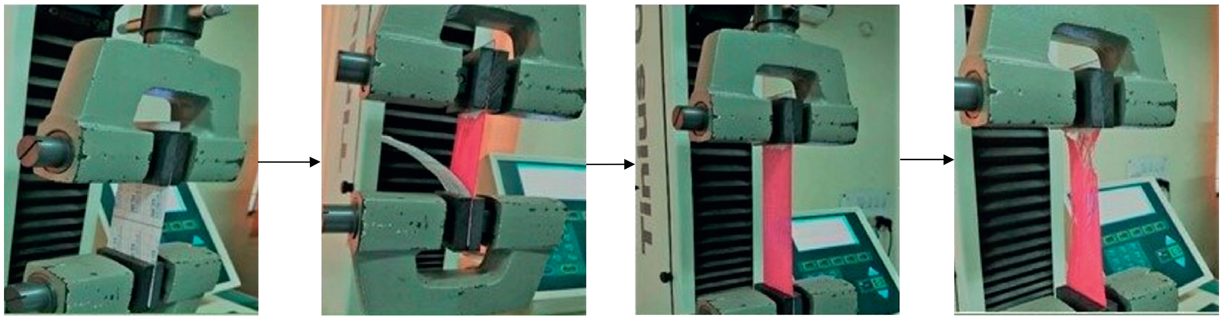


Figure 3: Three steps of sample mounting for a tensile test of tapes. (a) The tape is mounted with covered paper. (b) The paper is removed from gauge length. (c, d)The test is run up to failure.

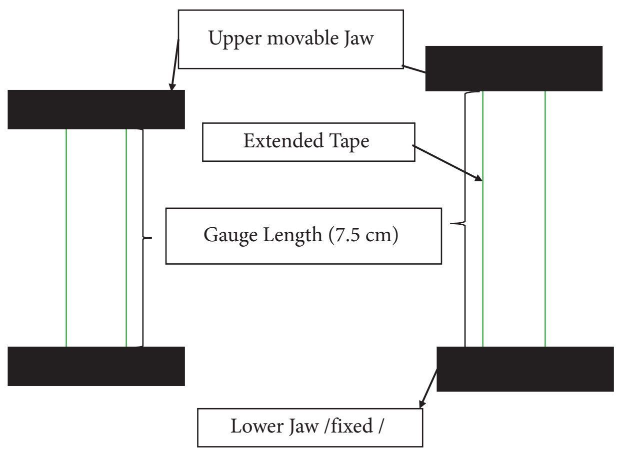


Figure 4: Method of the stress relaxation test under 25% and 50% level of extension.

been selected: 70 mm/min and 100 mm/min. The stress relaxation considers the change of length after 300 cycles and analyzes the effect of strain value on the holding performance of the therapeutic tape. The test was conducted at room temperature and under constant min-max load (300–400 gm).

(3) Temperature Variation. For this test, two temperatures at 25°C and 50°C have been selected which are designated minimum and maximum temperature, respectively. The other parameters associated with the study are constants like strain rate (100 mm/min) and min-max load (300–400 gm). The test was performed on a tensile testing machine with a heating chamber which is shown in Figure 5. The precision of the heating chamber rate is 4°C per min with a maximum temperature of 100°C and a minimum temperature of 10°C.

2.3. Analytical Methods

2.3.1. Percentage of Stress Reduction. The therapeutic tape was subjected to a stress relaxation test under a static condition. The obtained response forces (N) (tape resistance) were measured as a function of relaxation time. The peak force and the force after the given time were obtained from each extension value which is the recorded data. Then, the stress (N/m^2) reductions are calculated. The achieved result was used to understand the effect of extension value on the stress relaxation behavior of the tape.

2.3.2. Percentage of Elongation. During the cyclic test, therapeutic tapes under different temperatures, loads, and strain rates were implemented. In all cases, we observed an increase in the gauge length of each tape as the number of cycles increased.

3. Results and Discussion

3.1. Physical and Mechanical Characteristics

3.1.1. Physical Characterization. During physical characterization of therapeutic tape, some constructional parameters such as linear density of threads, thickness, and mass per unit area (GSM) of the tapes with and without adhesive were analyzed.

The test was performed under RH of 65% and a temperature of 27°C. The results are tabulated in Table 2. According to the analysis, we have confirmed that all the tapes have a weave structure and are made of different compositions of cotton with lycra and different counts of yarns as shown in Figure 6. The thicknesses of all the tapes were measured before and after the removal (washing) of the

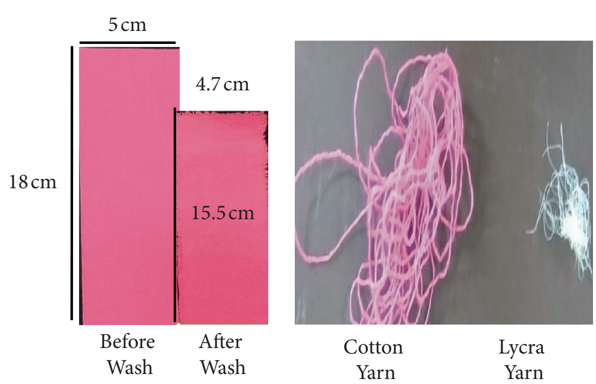
(a) (b)

Figure 5: (a) Tensile testing machine with the heating chamber and (b) sample mounting position.

Table 2: Physical properties of tapes before and after washing the adhesive.

S. no.	Sample code	Warp/weft yarn count (Ne)	Percentages of cotton and lycra (%)	Thickness (mm)		GSM (gm)		Length × width (cm)	
				Before washing	After washing	Before washing	After washing	Before washing	After washing
1	KT1	18/15	92.2/7.8	0.53	0.63	232	186.4	18×5	15.5×4.7
2	KT2	21/15	95.5/4.5	0.48	0.68	209.2	202.1	18×5	14.8×4.4
3	KT3	17/13	96.6/3.4	0.53	0.63	234.4	216.6	18×5	14.3×4.3
4	KT4	17/17	91.2/8.8	0.58	0.69	276	248	18×5	16.4×4.7

*Ne: English cotton count.



(a) (b)

Figure 6: (a) Tape after wash and before wash. (b) Cotton and lycra yarn.

adhesive. The result shows as the thickness of the tape after washing the adhesive is higher than before removing the adhesive. This may be because of the swelling effect of cotton yarn caused by running water and adhesive by itself also creates compactness between the yarns as well as the fibres. While fabric mass per unit area (GSM) is greater for samples with adhesive than that of samples after washing adhesive. Among all the tapes, KT4 (Mueller tape) showed an overall higher thickness and GSM value; this is due to the higher shrinkage properties of cotton yarn after washing and drying. KT3 and KT4 exhibit lower and higher shrinkage among the samples. Figure 6 shows cotton and lycra taken out from the tape for analyzing the percentage of composition of each yarn in the sample. The result indicated that the percentage of lycra in the sample is higher on KT4 and lower on KT3. Combining these two yarn types increase the ability to stretch, moisture wicking, and comfort properties of the fabric. In turn, these may also affect the properties of elastic therapeutic tapes.

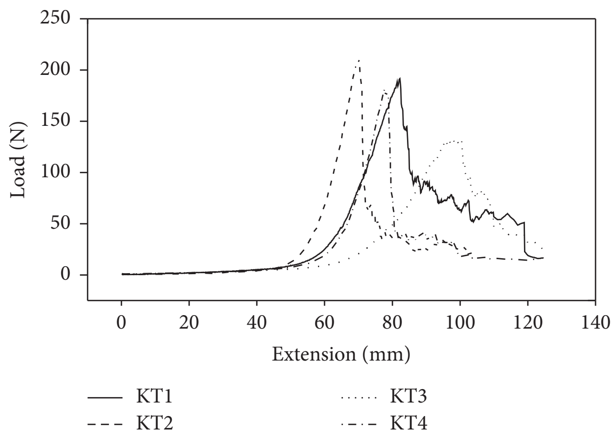


Figure 7: Tensile characteristics of each tape.

3.1.2. Mechanical Characterization. The tensile test was performed for all the tape samples to know the mechanical characteristics such as breaking load and breaking elongation of the samples in order to decide further parameters for any other kind of tests. The results of the tensile test for each tape sample are shown in Figure 7 and tabulated in Table 3. Figure 7 shows the force versus extension graph of each tape. The graph depicts that KT2 has the highest breaking strength but the lowest extension at break compared to that of the other tapes. Conversely, KT4 has the lowest breaking strength and the highest extension value as shown in Table 4. All the manufacturers mentioned that the ability of the tapes to stretch is about 120% to 140% of their original length but, according to these outcomes, only KT2 meets the standard while the other tapes have lower values than the standard values. So, it can be suggested that manufacturers should consider the mechanical properties of the tapes in the fabric point of view.

3.2. Relaxation Behavior of the Therapeutic Tape under Static Condition. All the tape samples exhibited stress relaxation under different extended rates. Table 3 shows the stress relaxation behavior of therapeutic tape for the samples. All the samples exhibit stress relaxation under an extended state; that is, the maximum stress is going to decrease with an increase in time. The variation of stress relaxation as a function of time was calculated according to the equation [2]. During 25% of extension, the rate of reduction of stress is more dominant between 4 and 600 sec, whereas for 50% extension, the stress reduction is more dominant between 4 sec and 1000 sec. After that, the rate of stress reduction is lower and then becomes almost constant for a longer period, as shown in Figure 8. In both extended cases, the tape sample easily gets relaxed, which clearly showed their viscoelastic behavior. This is because the internal stress at a higher load reached a peak and then reducing or relaxing over time under a fixed level of elongation. As shown in Table 4, the percent of stress reduction at 50% extension is higher than the stress reduction at 25% extension state. It is obvious that increasing the extension level on the tape by applying higher force leads to an increase in the internal stress in the structure of yarns and fibres and the fabric becomes degraded.

3.3. Relaxation Behavior of the Therapeutic Tape under Dynamic Condition. All the samples were tested under dynamic repetition conditions with various loads, rates of extension, and temperatures. The elongation value of all samples after 5, 50, 100, 300, and 500 cycles has been selected and the percentage of elongation after 300 cycles has been calculated using the equation from Bosman and Piller [3].

3.3.1. Effect of Load and Strain Rate. All tape samples exhibited stress relaxation under the same applied load and the same strain rate, as given in Table 5. The result shows elongation as a function of cyclic numbers. In all cases, the elongation behavior has increased for between 5 and 100 cycles and after that, it becomes slowed. It is known that the elongation behavior depends on both the value and duration of the cyclic loading-unloading state. As a result, the percentage of elongation is higher at 400–200 gm and lower at 150–100 gm of the cyclic loading-unloading state (see Table 5). The tape sample is subjected to two different strain rates over a varying number of cycles (at constant cyclic loading-unloading state). It is observed that, for both strain rates, the elongation rapidly increased for the first 50 cycles and after that, the elongation speed is reduced. The percentage of elongation at the lower strain rate is higher than that of the higher strain rate. This may be because when the fabric extended for a longer duration, its mechanical properties will be damaged more. Therefore, increasing the stress in the structure as well on the yarns and fibres leads to an increase in the stress relaxation behavior of the therapeutic tape.

3.3.2. Effect of Temperature. Figure 9 and 10 show the effect of temperature at a constant speed and constant cyclic loading-unloading condition on the tape movement. In both cases, the elongation increases rapidly in the first 150 cycles and then its rate slows down. The percentage of elongation under 50°C temperature is higher than that under 25°C

Table 3: Maximum breaking load and extension at break in the warp direction.

S. no.	Sample code	Max load (N)	Elongation at break (mm)	Max extension (%)	Strength of standard deviation
1	KT1	178.2	78.6	104.8	8.20
2	KT2	211.25	70.25	93.67	6.01
3	KT3	191.6	82.2	109.6	8.89
4	KT4	132.6	100.35	133.8	7.64

Table 4: Observations of the stress relaxation experiment in the warp direction.

Extension (%)	Sample code	Maximum stress (N/m^2)	Time max. stress (s)	Stress (N/m^2) at time (s) $t = 15$	$t = 60$	$t = 600$	$t = 1800$	$t = 3600$	Reduction after 1 hr. (%)	Standard deviation
25	KT1	54.08	3.9	41.8	36.9	31	27.3	27.06	50	6.42
	KT2	51.04	3.9	40.6	37.0	30.5	28.3	25.49	50.1	6.27
	KT3	58.42	3.9	49.7	47.4	43.1	41.0	38.46	34.17	4.59
	KT4	47.56	3.8	38.3	36.9	33.39	31.4	33.07	30.47	2.9
50	KT1	139.48	7.6	105	91.4	80.08	80.0	77.48	44.45	17.73
	KT2	139.43	7.5	102	89	77.79	76.7	76.66	45.02	16.5
	KT3	139.81	7.6	118	109	97.81	93.5	91.72	34.4	29.24
	KT4	118.48	7.6	97.4	88.7	78.16	73.4	69.14	41.64	17.54

*Initial length of the tapes (at $t = 0$) = 7.5 cm.

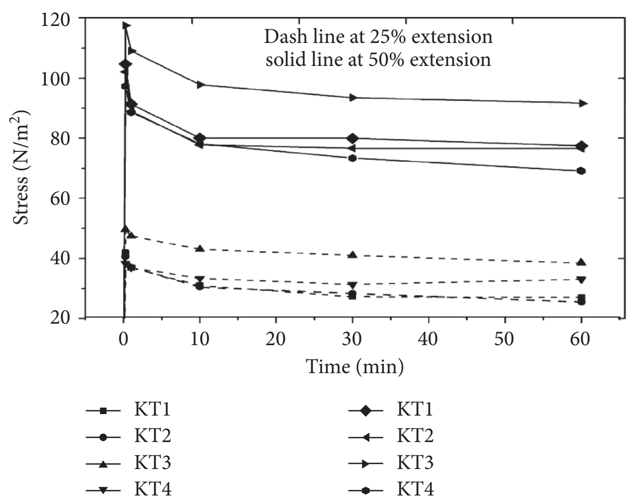


Figure 8: Stress response of the therapeutic tape under two levels of extension.

Table 5: Elongation after number of cycles in the warp direction.

S. no.	Loading force (gm)	Unloading force (gm)	Final length (cm) after N cycles $N = 5$	$N = 50$	$N = 100$	$N = 300$	$N = 500$	Elongation (%) after 500 cycles	Standard deviation
1	150	50	7.6	7.65	7.7	7.95	8.2	9.34	0.31
2	150	100	7.6	7.7	7.85	7.9	8.15	8.67	0.26
3	400	200	7.7	7.85	7.95	8.1	8.4	12	0.33
4	400	300	7.65	7.8	7.9	8.05	8.25	10	0.28

*Initial length of the tapes at $t = 0$ is 7.5 cm and the strain rate is 70 mm/sec.

temperature as shown in Figure 10. This may be due to the increase in the temperature that causes a decrease in the strength value of the yarn and the fibre in the structure. So, it leads to an increase in the relaxation state. Hence, temperature is one of the major factors for holding the performance of the therapeutic tape.

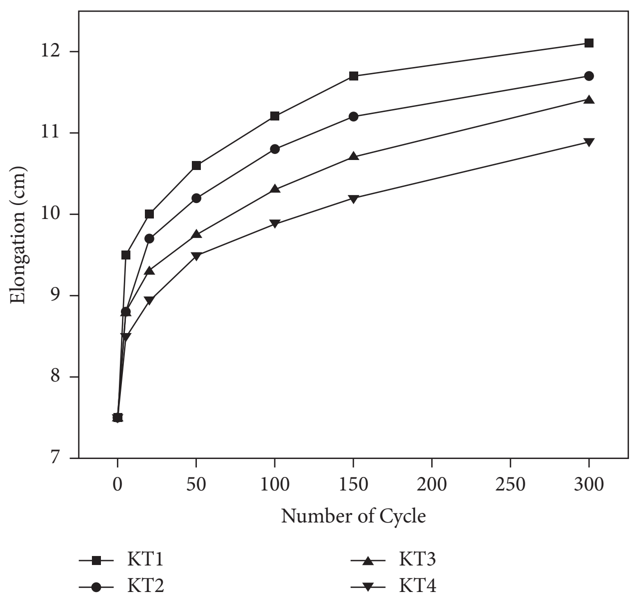


Figure 9: Elongation behavior of therapeutic tapes under 25°C.

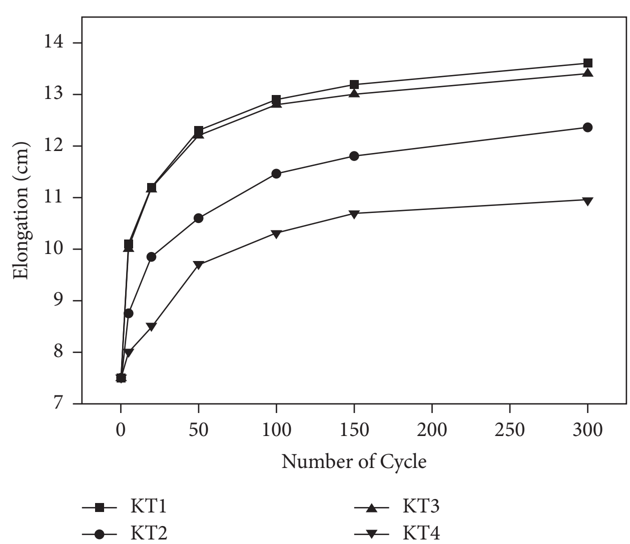


Figure 10: Elongation behavior of therapeutic tapes under 50°C.

4. Conclusion

In this study, the stress relaxation behavior of therapeutic tape under a static and dynamic condition with various parameters is investigated. Due to the cyclic loading-unloading condition, the holding performance of materials deteriorates. As a result, the tapes' therapeutic efficacy will deteriorate over time. For such products, a standard for replacement time must be developed.

The efficiency of tapes degrades faster at higher extension. As a result, if the product is utilized at a high extension, it will need to be replaced regularly. Under static and dynamic conditions, the therapeutic tapes show diverse responses. Internal stress loss is higher under dynamic conditions than it is under static conditions. As a result, dynamic patients necessitate different approaches and evaluations than static ones.

Furthermore, at higher temperatures, lower strain rates, and longer cyclic loading-unloading conditions, stress relaxation rises. This suggests that when the therapeutic tape is applied to patients for a prolonged period of time, these factors may interact to determine total efficacy.

Data Availability

The data supporting the findings of this study are all presented within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

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