An Experimental Analysis of Stress Relaxation in Nonwoven Fabrics

Sajid Ahmed Qureshi

ABSTRACT - The current research deals with an analysis of stress relaxation in nonwoven fabrics with different gsm values with a view to understand how these nonwovens behave under an applied stress for a given load over a constant period of time. An electronic stress relaxation tester was designed indigenously for this purpose which works on the strain gauge principle of measuring loads applied to the specimen at any given instant of time during the experiment. The respective stress values were calculated for corresponding load values for each specimen with every thirty seconds passage of time. The results obtained were graphically analyzed and it was revealed that the stress relaxation percentage was significantly different for the same nonwoven materials but with different gsm values. It was observed that nonwovens do possess the property of decaying the stress generated due to external loads and the extent to which this happens depends to a considerable extent on the gsm of the structure along with other factors like type of fibers and type of bonding.

Index Terms – bonding, gsm, nonwovens, load, stress relaxation, strain gauge, stress decay;

1. INTRODUCTION

Textile materials being visco-elastic in nature do respond with time to the external loads and stress. A material which is stressed decays with respect to time. This phenomenon would be exhibited even at very low stress levels. This property is basically related to the basic structure of fibers and packing of the fibers in the yarns and fabrics. This property also dictates the usefulness of fibers in its subsequent use. Elastic recovery, resilience, plasticity, creep and stress relaxation are all concerned with the dimensional stability of a fiber, yarn or fabric under the action of mechanical forces, and they are useful in evaluating functional properties of a fabric. For the purpose of investigating a mechanical property, four main types of deformations can be distinguished namely stretch, twist, bend and compression. These result in tests which are called tensile, torsional, flexural and compressive, respectively. The measurements are associated with parameters like stress and deformation. Time is an important factor when considering the relaxation between stress and strain particularly in textiles. This means that we must always deal with the stress, strain and time behavior. It is desirable to keep one of the variables at a constant value while studying the effect of the other two.

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Stress relaxation is one of the areas where an extensive work has been carried out which continues to attract research workers. Study of stress relaxation calls for both good instrumental technique and patience since it is a time dependent test. Quite often the stress relaxation has been measured using universal tensile testing instruments like Instron. Working with Instron needs operative skill and is also quite expensive. A standalone instrument to measure the stress relaxation is not available. In recent years electronics and computers have been playing a good role in the field of textiles. An effort has thus been made to design, develop and fabricate a low cost electronic stress relaxation tester which can be interfaced with a computer system to get instantaneous results and comparative statements.

2. STRESS RELAXATION PHENOMENON

Some of the aspects associated with stress and relaxation phenomenon of visco-elastic materials is mentioned here under.

Visco elasticity is concerned with materials which exhibit strain rate effects in response to applied stresses. These effects are manifested by the phenomenon of creep under constant stress and stress relaxation under constant strain. These time dependent phenomena may have a considerable effect on the stress distribution developed in a specimen; such as thick tube made of visco elastic material subjected to prescribed loads or prescribed surface displacements. The stress and/or strain at specific point in the material may vary significantly with time even though the applied forces remain constant. In order to be able to predict the

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change in stress and strain with the time a visco-elastic stress analysis method is needed.
The behavior of an individual fiber under a gradually increasing applied force is completely expressed by the load elongation curve with its end point breakage. In most physical and engineering applications load is replaced by stress, defined as:

Stress = Load / Area of cross section in N / Cm^2

To take account of length of the specimen, the elongation is expressed as tensile strain or percentage extension.

Tensile Strain = Elongation / Initial Length

Load elongation curves become stress-strain curves by a change of units, without affecting the shape of the curves.

2.1 Relaxation

Visco elastic materials subjected to a constant load will relax under constant strain, so that the stress gradually decreases. From a study of three time dependent responses (creep, recovery, relaxation) the basic principles governing the time-dependent behavior under loading conditions may be established.

In actual practice, stress or strain history may approximate one of the three time dependent responses or a mixture i.e., creep and relaxation may occur simultaneously under combined loading or the load or strain history may be cyclic or a random variation. Observation of the relaxation of stress at constant strain is not all that simple to interpret theoretically, because the external geometry of the specimen remains unchanged throughout the test.

To understand the stress-relaxation phenomena which call for inducing the stress in the material by subjecting it to a certain amount of deformation and then to record the stress in the material as the time progresses, various methods can be employed.

It is proposed to have a strain gauge which helps to transduce the stress present in the material which can be read conveniently on a digital panel meter. The advantage would be that the information can also be fed to an analog processor or a digital processor and auto recordings can be obtained.

3. Constructional Details

The methodology adopted in the fabrication of the electronic fabric stress relaxation tester is briefed here. It involves a co-ordination of the three following segments:

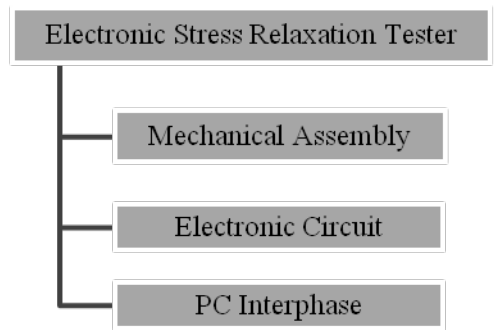

Fig. 1. Instrument Segments

In general, almost all instruments have similar functional elements which are depicted in the following flow chart. We can also describe both, the operation and performance of measuring instruments in a generalized way without considering the specific physical hardware. The operation can be described in terms of functional elements shown below:

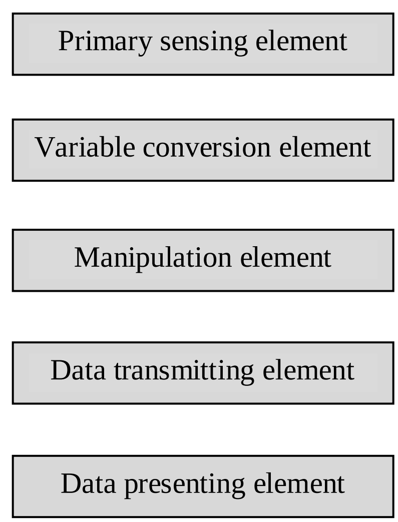

Fig. 2. Important Functional Elements

3.1 Measurand

This is the physical quantity which is actually measured. It may be any physical medium such as pressure, temperature, load, speed etc.

3.2 Primary Sensing Element

It is element which first receives energy from the measurand and produces an output depending on the measured quantity. This elements in the instrument is actually known as a transducer or load cell. While sensing the measurand, the primary sensing element always extracts the same amount of energy from the measurand to which it is subjected to. Strain gauges are used as the primary sensing element or transducer in the electronic stress relaxation tester.

3.3 Variable Conversion Element

The output of the primary sensing element is a variable such as voltage or change in resistance, inductance, capacitance etc. For the instrument to perform necessary the function, it is essential to convert this variable which contains the information of the original signal. An element that performs such kind of operation is termed as variable conversion element.

3.4 Variable Manipulation Element

Sometimes it may be necessary to manipulate the signal from the variable conversion element, say a change from milli-volts to a corresponding change in volts. Thus an electronic amplifier which performs such type of manipulation may be included as the variable manipulation element.

3.5 Data Transmitting Element

It may sometimes be necessary to transmit the data from one place to other. The element which performs this task is called a data transmitting element. The data transmitting element may be as simple as a co-axial cable or as complex as a telemetric system.

3.6 Data Presenting Element

If the information has to reach the observer with a view to monitor or control the signal must be put into a recognized form for human senses such as audio signals, scales, monitors etc. An element that performs this task is called the data presenting element.

4. Load Cell or Transducer

Load cells contain strain gauges arranged in a suitable form and bonded onto an elliptical ring surface. Strain gauges in a transducer contain a resistance wire which is wound in a specific fashion and enclosed a backing material to avoid atmospheric effects. The deformation of strain gauge resistance wire causes a change in its length and area of cross section. Since resistance of a wire depends upon its length and area of cross section, loading of load cell causes changes in resistance of strain gauges. When the strain gauges are not loaded and mounted in the arms of the Wheatstone's Bridge, there should not be any output at the output terminals of the bridge. The input terminals are given a D.C. excitation voltage and the output terminals are connected to an amplifier with digital panel meter to display the output. So, when the input terminals of the bridge give an input value, the output terminals should read zero voltage i.e., it's a balanced bridge. Whenever the load cell is subjected to a load, because of change in resistance of strain gauge resistance wires, the bridge circuit will get unbalanced and the output terminals read some voltage which is fed to an amplifier.

TABLE 1
LOAD CELL SPECIFICATIONS

Range	0-30 Kg
Type	Ring type
Sensor	Resistance type strain gauge
Bridge configuration	4 Arm
Sensitivity	0.2 mV/FSD
Output Connection	Through 4 core cable
Temperature	0-55^0 C
Linearity and hysteresis	$\pm$ 0.1% FSD

4.1 Strain Gauge Circuit

Strain gauges are bonded on to an elliptical circuitry ring surface and these strain gauges are connected in the form of wheat stone's bridge as shown in the fig. The output of the bridge is connected to the digital display amplifier through the cable supplied.

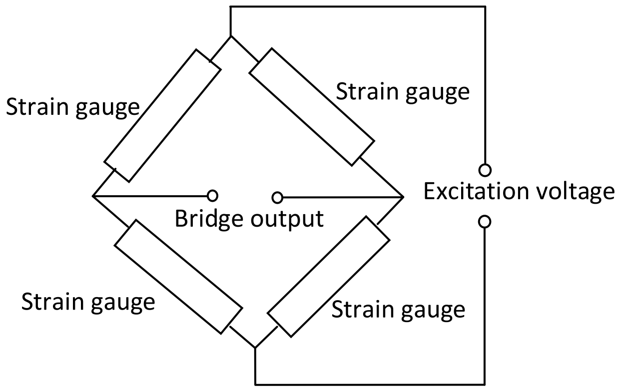

Fig. 3. Wheatstone's Bridge

4.1.1 Selection Criteria for Strain Gauges

- Strain gauge wires should have high sensitivity in order to keep the current flow and consequent heat dissipation low.
- Strain gauge wires should have low temperature co-efficient of resistance. Thus gauge sensitivity to ambient temperature is low.
- Gauge wire should have a stable resistance.
- Gauges should have high gauge factor or unit change in resistance per unit change in load should as high as possible.
- Strain gauges should have low thermal e.m.f at copper terminals.
- Wire should have creep strength and yield stress.
- Gauge should have low hysteresis in the stress cycle.
- Gauge should be small in size in the order of 1 mil so that appreciable elongations will be produced with the forces measured.

4.2 Digital Display Amplifier

It is the other main component of stress relaxation tester. As stated earlier the bridge output from a load cell has to be fed to an amplifier which amplifies the signal output on a digital panel meter which is calibrated to read the stress in engineering units (Kg). The instrument operates on a 230 Volts, 50 Hz A.C. The output from the load cell has to be modified before it becomes usable and satisfactory to drive the signal presentation stage which is the final stage of the measurement process. The final stage of measurement consists of indicating, recording, displaying, data processing or controlling elements. The stress sensed by load cell is amplified by processing through the electronic circuit.

4.2.1 Digital Output

The digital instrument indicates the value of the measurand in the form a decimal number. In electronic stress relaxation tester the loading of load cell by any means results in the corresponding load value at the digital display panel. The digital panel meter in this instrument is calibrated to read the load directly in grams.

5. Experimental Procedure & Results

The instrument has a fixed upper jaw connected to the load cell and a movable lower jaw. The specimen to be tested is first taken for the breaking extension test using the fabric tensile strength tester. Half of this breaking load is taken for extending the fabric to produce a stress which will result in an ideal relaxation. The specimen is fixed between the 2 jaws by operating the screws. Care must be taken to see that the sample to be tested is firmly gripped between the jaws without any twist and the knobs should be tightened properly to avoid any slippage at the jaws. Specimen length can be adjusted by fixing the moveable lower jaw to the required position.

Load is applied to the specimen by pulling the lower jaw downwards till we get the required load which gets displayed on the digital panel meter. The knobs of lower jaw is then to be tightened. Before starting the experiment the instrument has to be switched on for 2 minutes to warm up and then the load reading gets set to zero. As soon as the lower jaws position is fixed the reading on display and the time are automatically recorded by the computer system. The time-stress curves at fixed intervals are plotted automatically online.

Particulars of experiment:

Reading interval: 30 sec; Specimen width: 1 inch;
Gauge length: 8.0 inches.

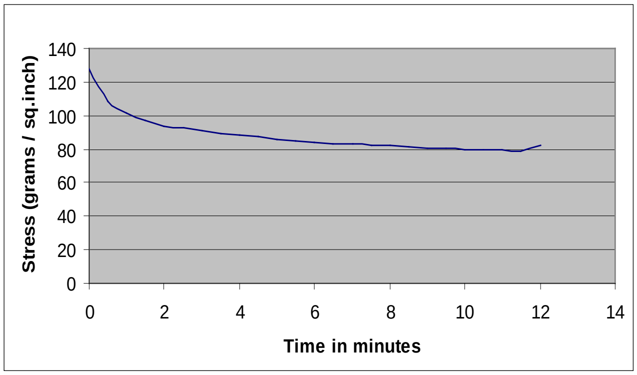

Fig. 4. Time Stress Curve: Sample No. 1 – 50 gsm

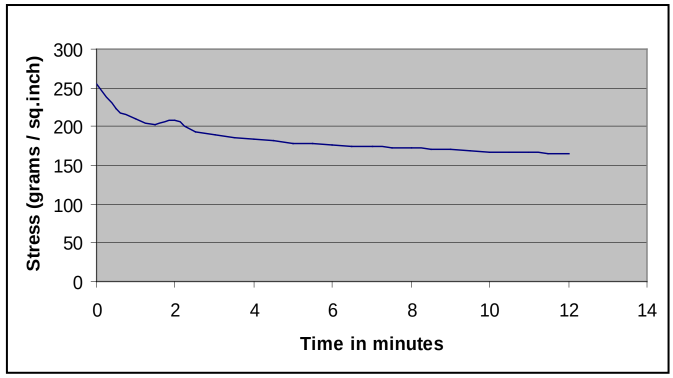

Fig. 5. Time Stress Curve: Sample No. 2-60 gsm

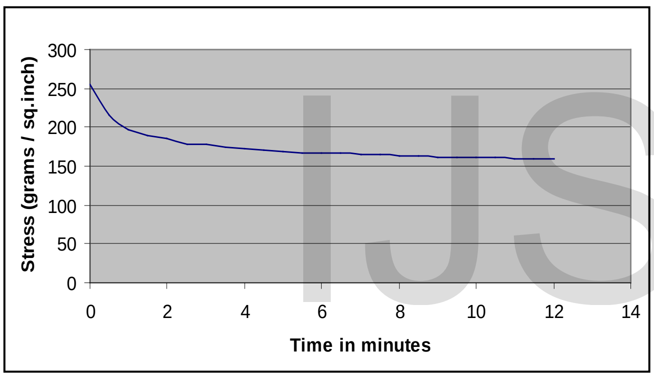

Fig. 6. Time Stress Curve: Sample No. 3 – 70 gsm

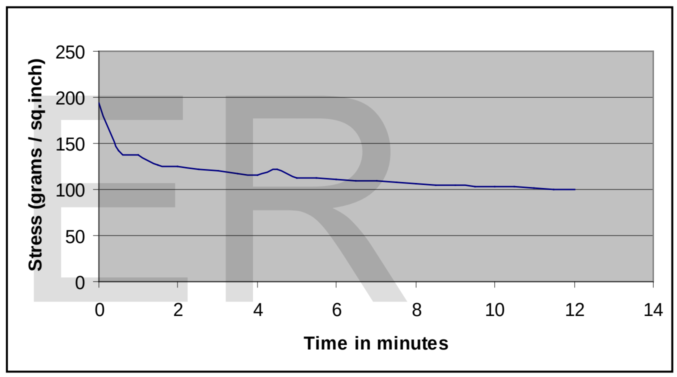

Fig. 7. Time Stress Curve: Sample No. 4 – 80 gsm

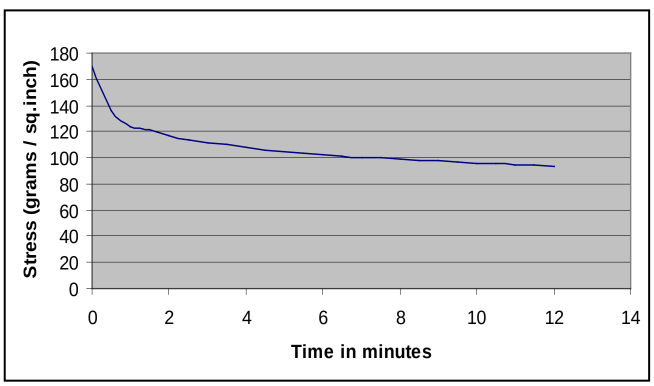

Fig. 8. Time Stress Curve: Sample No. 5 – 90 gsm

TABLE 2
EXPERIMENTAL RESULTS OF STRESS RELAXATION V/S TIME

S.No	Time (Minutes)	Stress (grams/sq. inch) Sample1 (50 gsm)	Sample2 (60 gsm)	Sample 3 (70 gsm)	Sample 4 (80 gsm)	Sample5 (90 gsm)
1	0	127.500	255.000	255.000	193.750	170.000
2	0.5	108.125	222.500	216.125	141.500	136.120
3	1.0	101.250	209.250	197.625	137.750	124.000
4	1.5	97.375	202.375	190.250	126.250	121.125
5	2.0	94.000	209.000	185.250	124.250	116.750
6	2.5	92.750	192.375	178.000	121.500	113.750
7	3.0	91.250	189.000	177.500	120.620	111.500
8	3.5	89.375	186.250	175.000	117.750	109.875
9	4.0	88.000	183.750	171.875	115.500	107.750
10	4.5	87.375	181.250	170.500	121.120	106.250
11	5.0	85.500	179.000	168.750	113.000	105.000
12	5.5	84.875	177.750	167.625	111.750	104.000
13	6.0	83.750	176.750	166.875	110.500	102.500
14	6.5	83.125	175.000	166.125	109.870	101.750
15	7.0	82.750	173.750	165.250	108.750	100.250
16	7.5	82.375	173.000	164.500	107.750	99.875
17	8.0	81.875	171.750	163.750	106.750	98.625
18	8.5	81.250	170.625	162.875	105.250	98.000
19	9.0	80.625	170.000	162.125	104.370	97.375
20	9.5	80.500	168.750	161.375	103.750	96.500
21	10.0	80.000	167.750	160.875	103.120	96.125
22	10.5	79.875	166.750	160.375	102.500	95.500
23	11.0	79.375	166.500	159.750	101.500	94.375
24	11.5	78.750	165.625	159.375	100.250	94.000
25	12.0	82.375	164.875	158.875	100.000	93.625
% Relaxation		**35.45**	**35.34**	**37.69**	**48.38**	**50.00**

6. Conclusion

The experimental analysis reveals that nonwoven textiles do possess the inherent characteristic of minimizing the stress generated in them owing to the application of an external load on them. The results show that as time passes with the application of an applied load on the specimens, the stress starts to decay very rapidly in the initial stages and subsequently the rate of decay becomes gradual over a certain period of time, and ultimately reaches an equilibrium state after which no further decay in the stress levels is observed.

The amount of residual stress at this equilibrium stage is different for different specimens. The amount of relaxation can be indicated in terms of percentage of relaxation and it can be very well observed from the experimental results that different specimens exhibit different relaxation percentage. This can be attributed to various factor viz. the specimen composition, structure, type of bondage etc. This can also be attributed to the varying gsm values of the different specimens selected for the test.

The nonwoven samples with a higher gsm value have exhibited a better relaxation of stress as is evident from the results. This understanding of the relexation behavior of textile materials in very important when they are put to use for applications wherein they are subjected to a constant external load. It makes us to know in what way a given textile material is capable of overcoming the applied stress.

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