Effect of Fatigue on Welded and Sewn Nonwoven Filter Bags in Pulse-jet Air Filtration System

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Abstract: The present study aims at investigating the effect of the cyclic filtering/cleaning action simulating the accelerated fatigue test on both sewn and welded filter bags in the process of air filtration. Filter bag manufacturers are keen on economizing when producing and tailoring their brand products and thus the same piece may be offered at less price to perform an intended job. Life time for filter bag is considered vital in some industries, as frequent bag replacement imposes high operational costs and causes less marginal profits. In this study, eighteen polyester non-woven fabric samples were sewn and tailored using two types of sewing threads at three different stitch densities with 1, 2 and three stitching lines. On the other hand the same fabric was welded at three widths. The fabric used throughout the study was tested for its physical and mechanical properties before tailoring. The tailored bags were subjected to repeated stresses represented by cleaning cycles in a pilot scale bag house filter and the same properties were measured after each 5000 cleaning or pulsing cycles. The results show that 30000 pulsing cycles was a limit as the properties of the welded fabric bags started to deteriorate and become unsuitable to be used for controlling dust particles while the same properties of the sewn bags are still acceptable for higher number of cleaning cycles which can reach over 350000 considering 3-4 years life time.

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Key Words: Air filtration, Bughouse, sewn bags, welded bags Fatigue, Cleaning cycles, Pulsing, Bursting, Air permeability, Seam strength

1. Introduction

Technical textiles are one of the fastest growing segments in the textile world. Since the quantity of textile structures for technical applications as well as the range of applications themselves increase, the market for technical textiles grows from day to day[1].

Fabric filters can be categorized by several means, including type of cleaning (shaker, reverse-air, pulse-jet), direction of gas flow (from inside the bag towards the outside or vice versa), location of the system fan (suction or pressure), or size (low, medium, or high gas flow quantity). Of these four approaches, the cleaning method is probably the most distinguishing feature [2]. Parameters that affect cleaning include the amplitude and frequency of the shaking motion and the tension of the mounted bag. The first two parameters are part of the baghouse design and generally are not changed easily. The tension is set when bags are installed. Typical values are about 4 Hz for frequency and 2 to 3 inches for amplitude (half-stroke) [3].

Compared with reverse-air cleaned bags, the vigorous action of shaker systems tends to stress the bags more, which requires heavier and more durable fabrics. In the United States, woven fabrics are used almost exclusively for shaker cleaning [4]. When glass fiber fabrics were introduced, a gentler means of cleaning the bags, which may be a foot in diameter and 30 feet in length, was needed to prevent premature degradation. Reverse-air cleaning was developed as a less intensive way to impart energy to the bags. In reverse-air cleaning, gas flow to the bags is stopped in the compartment being cleaned and reverse (outside-in) air flow is directed through the bags. This reversal of gas flow gently collapses the bags toward their centerlines, which causes the cake to detach from the fabric surface. The detachment is caused by shear forces developed between the dust and fabric as the latter changes its shape. Metal caps to support the bag tops are an integral part of the bag as are several sewn-in rings that encircle the bags to prevent their complete collapse during cleaning. Without these rings, falling collected dust tends to choke the bag as the fabric collapses in on itself while cleaning [2].

An advantage of pulse-jet cleaning compared to shaker or reverse-air bag house is the reduction in bag house size (and capital cost) allowed by using less fabric because of higher gas-to-cloth ratios and, in some cases, by not having to build an extra compartment for off-line cleaning. However, the higher gas-to-cloth ratios cause higher pressure drops that increase operating costs. This form of cleaning uses compressed air to force a burst of air down through the bag and expand it violently. As with shaker bag house, the fabric reaches its extension limit and the dust separates from the bag.

Air escaping through the bag carries the separated dust away from the fabric surface. In pulse jets, however, filtering gas flows are opposite in direction when compared with shaker or reverse-air bag house (i.e., outside-in). One type of cartridge [5]. Contains an inner supporting core surrounded by the pleated filter medium and outer supporting mesh. One end of the cartridge is open, which allows gas passing through the filter from the outside to exit to a clean air plenum. Cleaning air is pulsed through the same open end, but in a reverse direction from the gas being cleaned. The other end of the cartridge is closed by an end cap. The manufacturing process requires strong, rigid joints where the end caps attach to the filter medium and cores.

Filter bag design depends on the system of filtration [6], the design includes a wide variety bag types with many details such as:

a) Bag top designs b)Bag bottom designs,

c)Top removal bag top designs, d)Bag bottom designs, and

e) Fabric selection for normal and specialty applications.

M. A. Saad and R. F. El-Newashy [7], studied the effect of stitch geometry on particle bypass in air filter bags. It was found that the most suitable stitch for the fabric weighed 200,300 g/cm^2 is SSw with needle count 90/14,suitable stitch for the fabric weighed 400,500 g/cm^2 is LSc needle count 80/11 and suitable stitch for the fabric weighed 600 g/cm^2 is LSb needle count 70/11.

Bag costs vary from less than 15% to more than 100% of the cost of the bare bag house (bag house without bags or auxiliaries), depending on the type of fabric required. This situation makes it inadvisable to estimate total purchased cost without separately estimating bag house and bag costs, and discourages the use of a single factor to estimate a cost for the combined bag house and bags**.** Filter bags are considered the most frequently replaceable part in pulse-jet system, which have a typical operating life of about 2 to 4 years [8].

Ultrafit company [9] provided a filtration system in which it is fully contained by using only welded seams throughout the filter bag, including the attachment of the collar to the bag, eliminating the potential for solids bypass. When a filter bag has stitching holes, resulting from sewn seams, the path of least resistance is through the holes and not the filter media. This is a weakness in design which compromises performance and yields inferior results. Welded Liquid Filter Bags have no sewn seams anywhere, eliminating solids bypass through needle holes.

1.1.Analysis of Stresses During Process of Cleaning Caged Fabric Filters:

Figure1 illustrates a schematic diagram of a pulse-jet cleaned bag house and cleaning cycles in figure 2. In conventional pulse-jet bag houses, bags are mounted on wire cages to prevent collapse while the dusty gas flows from outside the bag to the inside during filtration. Instead of attaching both ends of the bag to the bag house structure, the bag and cage assembly generally is attached only at the top. The bottom end of the assembly tends to move in the turbulent gas flow during filtration and may rub other bags, which accelerates wear. Often, pulse-jet bag houses are not compartmented. Bags are cleaned one row at a time when a timer initiates the burst of cleaning air through a quick-opening valve, this cyclic action is repeated every 10 minutes for a period of 3 to 4 years representing the bag life (total: over 300000 cycle). A pipe across each row of bags carries the compressed air. The pipe has a nozzle above each bag so that cleaning air exits directly into the bag. Some systems direct the air through a short venturi that is intended to entrain additional cleaning air. The pulse opposes and interrupts forward gas flow for only a few tenths of a second. However, the quick resumption of forward flow redeposit's most of the dust back on the clean bag or on adjacent bags. This action has the disadvantage of inhibiting dust from dropping into the hopper, but the advantage of quickly reforming the dust cake that provides efficient particle collection. According to the description given and literature, the filter fabric is subjected to many kinds of repeated mechanical stresses such as: tension and shear forces, wear and bursting pressure causing fatigue which leads to failure.

The present study aims at investigating the effect of the cyclic filtering/cleaning action simulating the accelerated fatigue test on both sewn and welded filter bags.

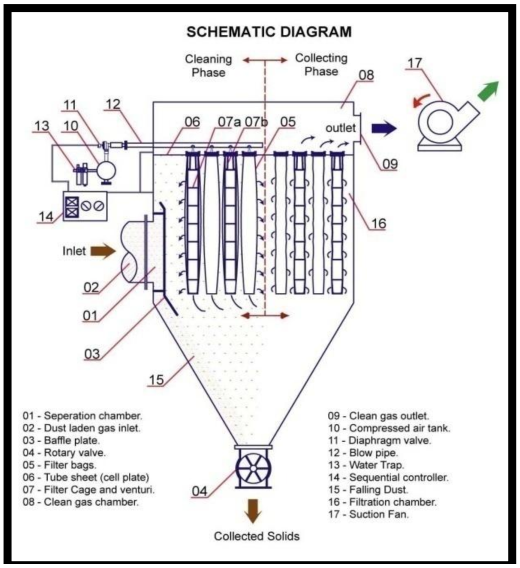

Figure (1) schematic diagram of a pulse-jet cleaned bag house and cleaning cycles

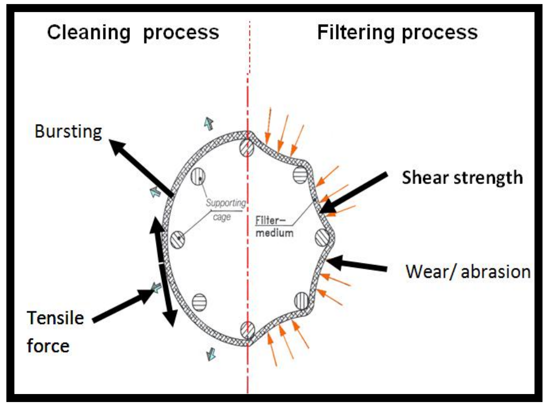

Figure (2) Mechanical Stresses and forces during filtering and cleaning in pulse-jet system

Accelerated fiber fatigue can be simulated in the laboratory by cyclically tensioning, bending, twisting, buckling a fiber, either individually or in a combined mode [10]. An example of the combined mode is bending a fiber over a pin, and then rotating the fiber or oscillating it to-and-fro over a fine wire mandrel. Figure (3) shows some examples of fiber fatigue simulation.

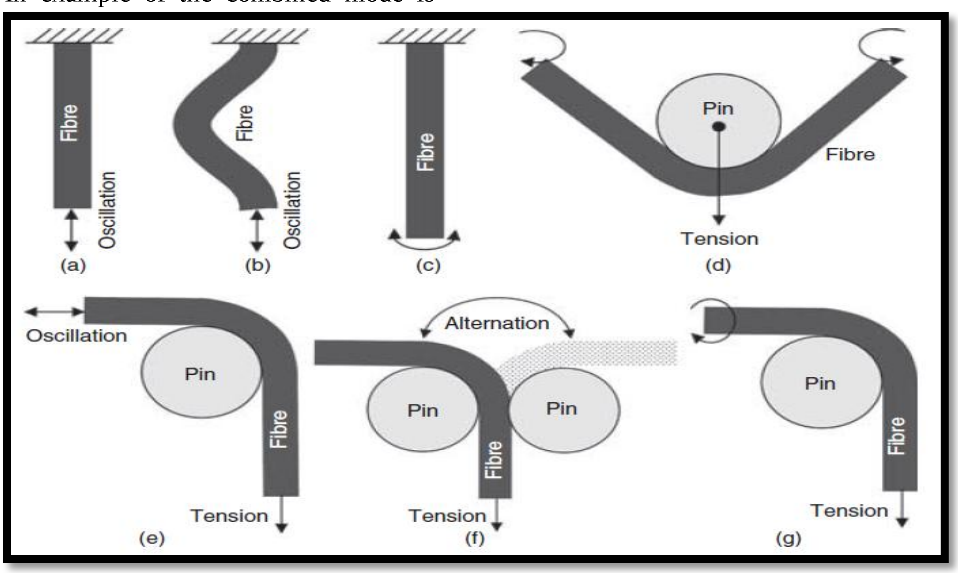

Figure (3) Examples of fiber fatigue simulation

2. Materials and testing methods:

The bag filter fabric material mostly used in industry was used throughout the present study; its technical specifications are as follows:

- Weight: 500 g/m^2.
- Thickness: 2.0 mm.
- Surface finish: Heat set/ calendered.
- Type of material: 100% polyester.
- Continuous operating temperature: 135 ◦c.
- Air-permeability: 190 dm^3/dm^2/min.
- Micron: 10.
- Bursting strength: 35 Kg/cm^2.
- Tensile strength: Longitudinal direction- 1600 N/5cm Crosswise direction - 1200 N/5cm.
- Elongation at break: Longitudinal direction- 22 % Crosswise direction- 24 %.

3. Sewing parameters:

3.1. Sewing yarns:

Two kinds of yarns were used to sew the fabric samples with three levels of stitch densities (5.7, 7.2and 8.5 stitch/cm).
The two yarns have the following specifications:

- Type A: Material- polyester100%, count 23 Ne, twist: 9.2T t/inch, tenacity 32.74 cN/tex, elongation at break 24.3%.
- Type B: Material: polyester100%, count: 23Ne, twist: 12.5t/inch, tenacity 18.05 cN/tex, and elongation at break 20.87%.

3.2. Sewing machine:

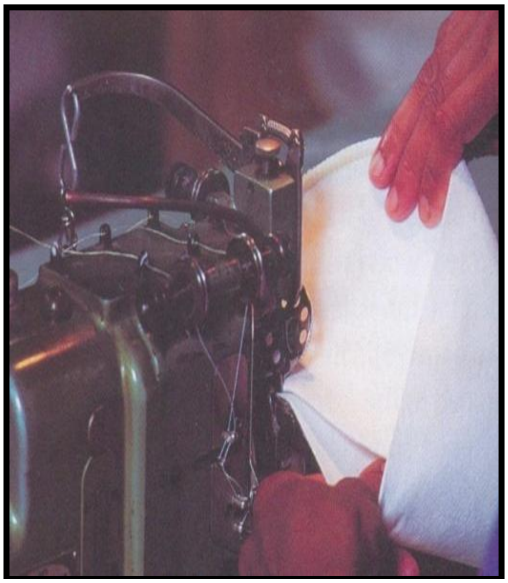

Figure 4 Discs (metal rings) are sewn to the filter bag with an over lock stitch

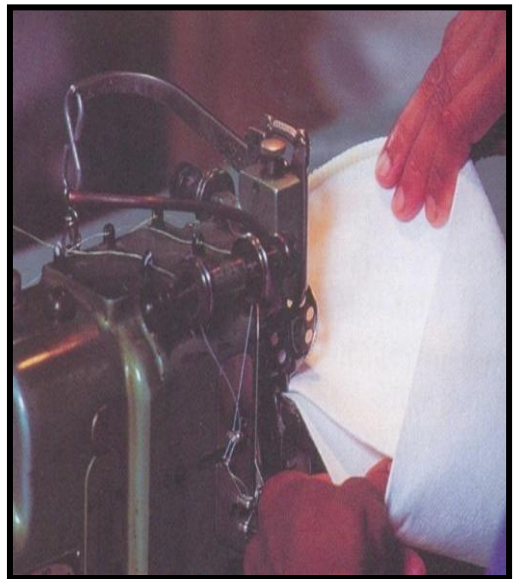

Figure 5 Anti-collapse rings into filter Bags using lock stitching

3.3. Stitch type:

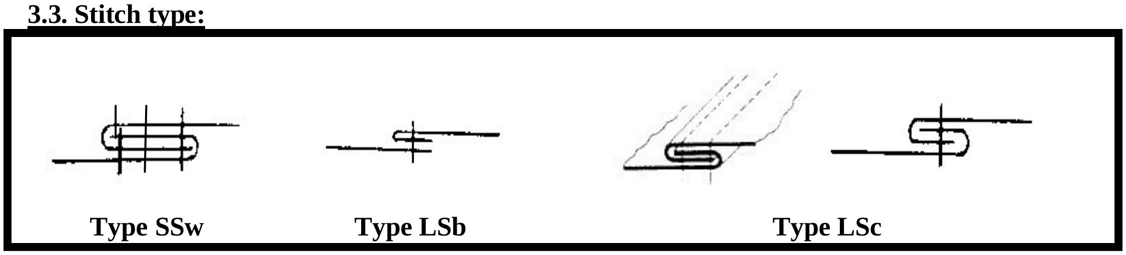

Figure 6: Seam examples

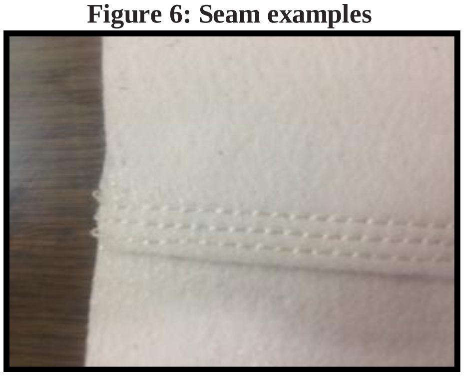

Figure (7): Three lines sewn filter bag

3.4. Welding machine:

The samples used throughout the present work were welded at a speed 9 m/min and 300 °C hot air temperature, the welding machine used is shown in figure (8) and samples produced are shown in figure (9).

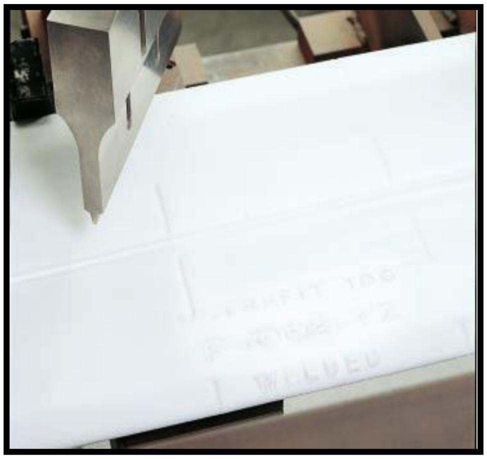

Figure (8): Fabric welding machine

Figure (9): Welded filter fabric

4. Filtration Unit:

The 21 fabric samples were tailored, sewn and designed as bags using the filtration unit shown in figure (10), this unit is designed with the following main parameters:

- Fan Capacity : 2000 m^3 / hr
- Air –to – cloth Ratio (A/C) : 100
- Number of bags : 20 (4 bags × 5 lines)
- Bag dimension (Φ) 0.21 m × 1.5 m (length)

This unit was used to test the sewn filter bags to resist repeated air compressed pulses at a pressure equal to 7 bar which is applied for industrial filtration units [11].

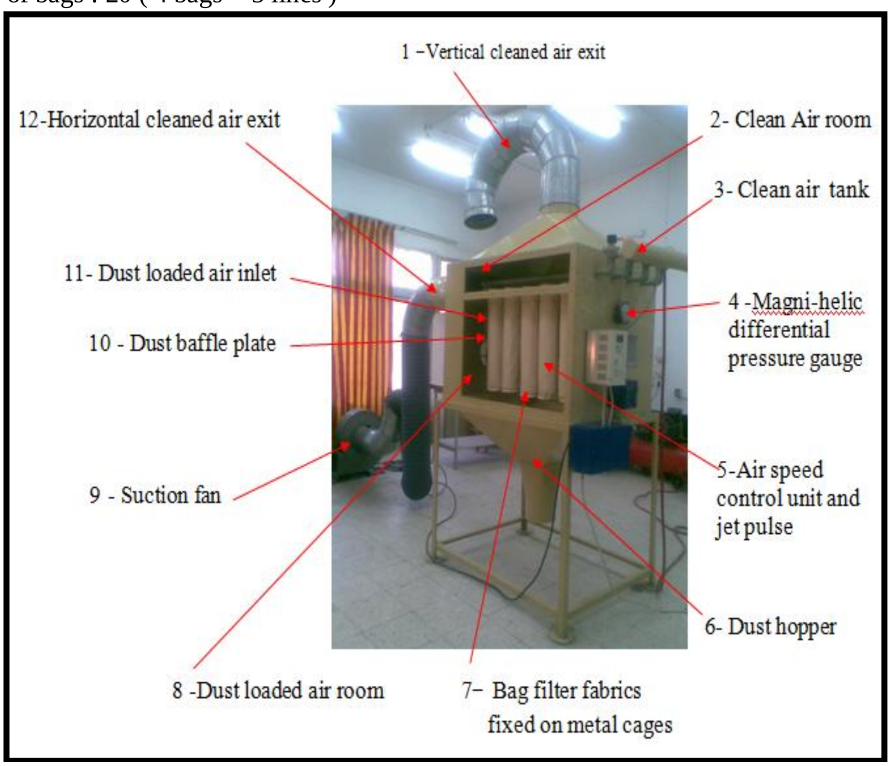

Figure (10): Pilot scale bag filter unit

5. Results and Discussions:

Figures (11) and (12) show the rate of air – permeability of the sewn parts with 1, 2 and 3 lines of stitching at zero pulses and a range of pulses from 5000 to 30000 pulses in steps of 5000 pulses for both types of sewing yarns A and B.

It is noticeable that the rate of air – permeability is higher in case of three stitching lines for both types of yarns (nearly 25-37 % increase) within the same stitch density, also the values of this typical property increases with stitch density. This may be referred to increasing numbers of pores due to stitching. A slight increase in air permeability (max. 3 $m^3/m^2/min$) due to cyclic cleaning pulses was obtained for 1, 2 and 3 stitching lines. Due to mechanical friction between metal cage wires and internal surface of filter fabric, abrasion bars occurred. However, the nature of filtration mechanism of air cleaning may avoid such effect due to formation of dust cake over the whole surcomfrance of the filter bag as long as the particle size is equal to or less than the holes made by stitching needles or within the fabric itself.

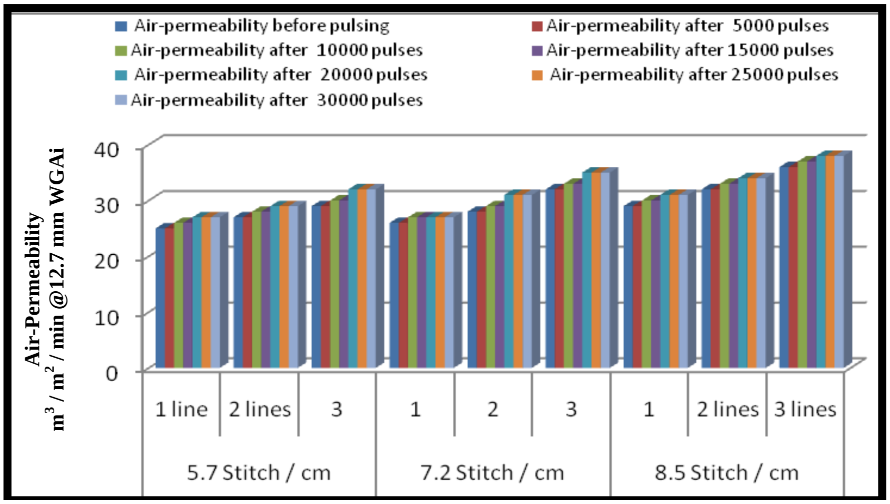

Figure (11) Air Permeability "Sewing yarn A"

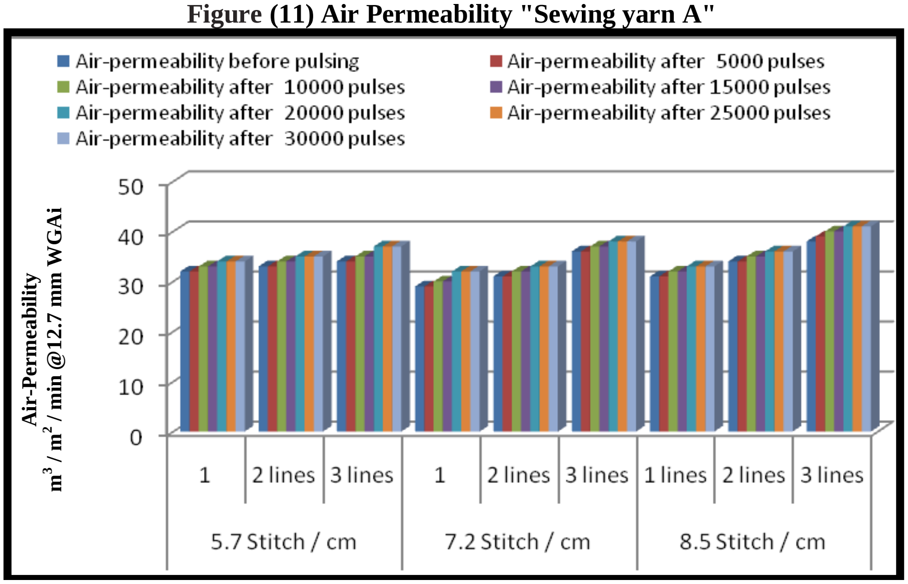

Figure (12) Air Permeability "Sewing yarn B"

Figures (13) and (14), show the effect of stitching lines on bursting strength of sewn parts at a range of cleaning pulses (0-30000) using both types of sewing threads A and B.

An average increase of 12% in bursting strength was obtained with the 3 stitching lines, while the value of this property remains constant due to fatigue effect represented by cyclic cleaning pulses equal to 7 bars which is far below the normal stress required to stretch the fabric until rupture, and that gives a sign for longer fatigue life of the sewn fabric. Increasing stitching density led to decreasing bursting strength, this is explained by severe rupture caused by needling effect.

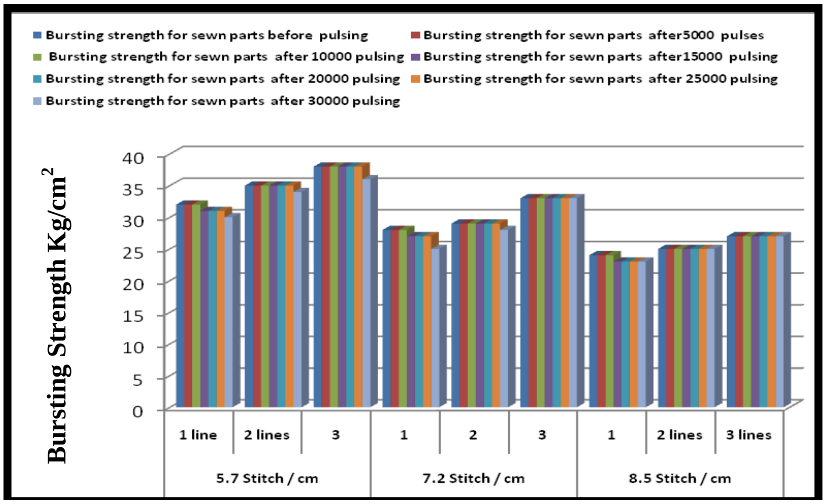

Figure (13) Bursting Strength (Sewing A)

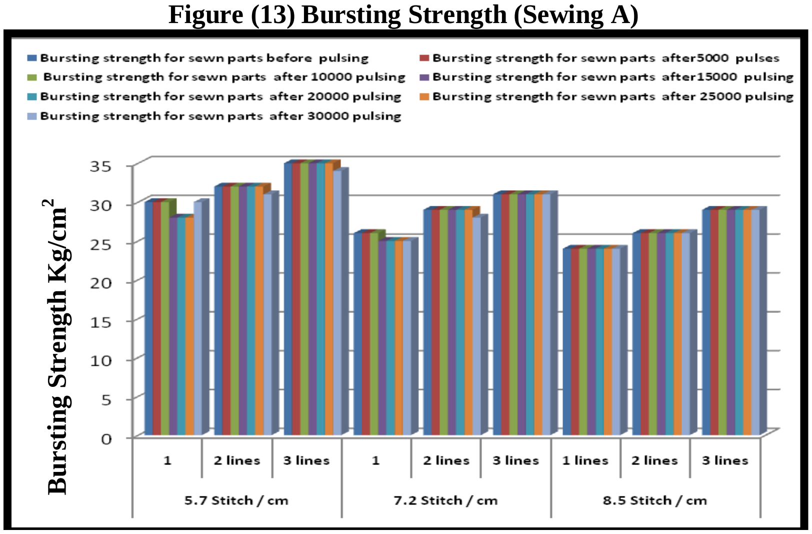

Figure (14) Bursting Strength (Sewing B)

Figures (15) and (16), show the effect of stitch density, number of stitching lines and cyclic cleaning pulses on fabric seam strength. In general, seam strength increases with stitch density and stitching lines. The fabric samples sewn with 1 and 2 lines were affected by the cyclic cleaning pulses, while the three stitching lines showed consistency of seam strength, these phenomena again agrees with the trend of bursting strength which gives a sign for longer fatigue life of the sewn fabric.

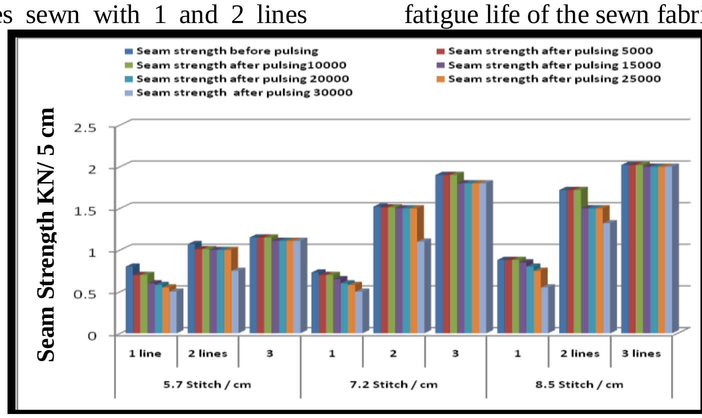

Figure (15) Seam strength (Sewing yarn A)

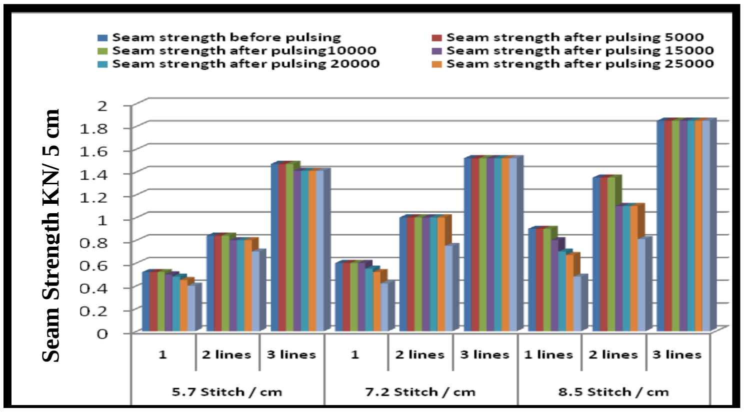

Figure (16) Seam strength (Sewing yarn B)

The effect of welding width and repeated stresses due to cyclic cleaning pulses on air-permeability, bursting and welding tensile strength is shown in figures (17-19).

In Figure (17), it is shown that increasing welding width caused an average decrease of 30% in air-permeability, while cyclic cleaning pulses led to gradual increase in air-permeability reaching 60% at 30000 cyclic over original permeability at zero pulses.

In practice this is very significant, since air-permeability beyond this limit may lead to particle bleed through the welded lines of the filter fabric.

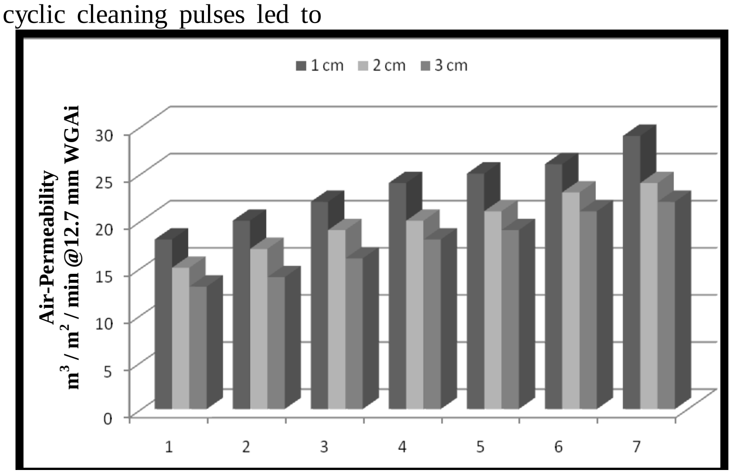

Figure (17) Welding Air-permeability

Similar trend for bursting strength is observed in Figure (18), increasing welding width give higher bursting strength of welded lines up to of 63%, while 38% decrease in bursting strength is occurred due to cyclic cleaning pulses at 30000 pulses.

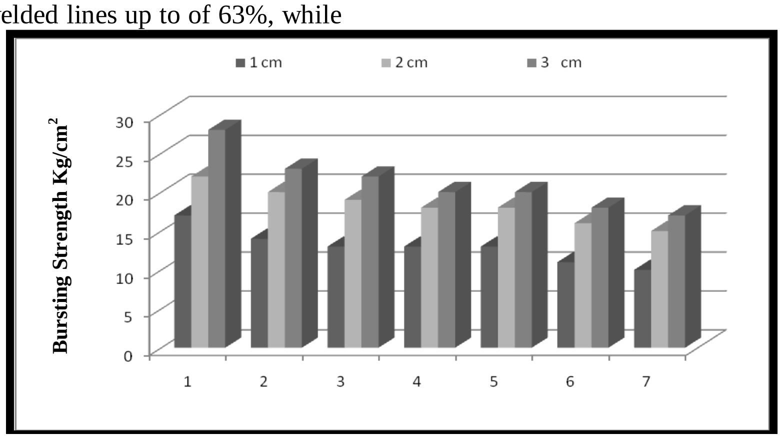

Figure (18) Welding Bursting strength

In figure (19), welding tensile strength increased by an average 63% due to increasing welding width, while 61% decrease of welding tensile strength is obtained due to cyclic pulses. When the fabric is welded, the melting point of the polymer used is reached which causes over stiffness along the welding line. The cyclic pulsing therefore may well result in cracks alongside and across the welding line, on the other hand sewing process does not cause this phenomenon. This may explain why the experiments were run up to 30000 cyclic pulses as a limit.

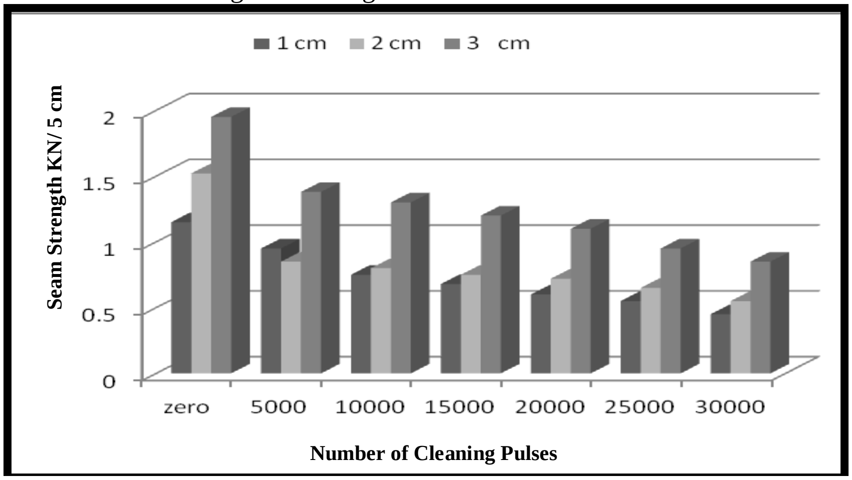

Figure (19) Welding Tensile Strength

6. Conclusions:

1. Air- permeability is higher in case of three stitching lines for both types of yarns (nearly 25-37 % increase) within the same stitch density, also the values of this typical property increase with stitch density.
2. A slight increase in air permeability (max. 3 $m^3/m^2/min$) due to cyclic cleaning pulses was obtained for 1, 2 and 3 stitching lines.
3. An average increase of 12% in bursting strength was obtained with the 3 stitching lines, while the value of this property remains constant due to fatigue effect represented by cyclic cleaning pulses equal to 7 bars.
4. Increasing stitching density led to decreasing bursting strength, this is explained by severe rupture caused by needling effect during sewing process.
5. Seam strength increases with stitch density and stitching lines.
6. Fabric samples sewn with 1 and 2 lines were affected by the cyclic cleaning pulses, while the three stitching lines showed consistency of seam strength.
7. Increasing welding width caused an average decrease of 30% in air-permeability, while cyclic cleaning pulses led to gradual increase in air-permeability reaching 60% at 30000 cyclic over original permeability at zero pulses.
8. Increasing welding width give higher bursting strength of welded lines up to 63%, while 38% decrease in bursting strength is occurred due to cyclic cleaning pulses at 30000 pulses.
9. Welding tensile strength increased by an average of 63% due to increasing welding width, while 61% decrease of welding tensile strength is obtained due to cyclic pulses.

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