

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

185,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Wing Tear: Identification of Stages of Static Process

Beata Witkowska¹ and Iwona Frydrych²

¹*Textile Research Institute,*

²*Technical University of Lodz,
Poland*

1. Introduction

In 1945 Krook and Fox (Krook & Fox 1945) analyzing photos of torn tongue shape samples distinguished and described the fabric tearing zone, i.e., the zone, which appears between both thread systems of torn fabric sample. The fabric tearing zone is limited by two threads of stretched thread system arising from the cut strips of torn sample, and the torn thread system being in the position “just before the breakage”. Krook’s and Fox’s research was an inspiration for the next researchers, who were interested in the fabric tearing. They have very often based their considerations on Krook’s and Fox’s conclusions.

The research was continued by Teixeira et al. in 1955 (Teixeira et al., 1955). They developed Krook's and Fox's (Krook & Fox, 1945) observations, and also formulated the theoretical equation, which described the tearing phenomenon.

In 1959 Taylor (Taylor, 1959) elaborated the mathematical relationship, which on the basis of fabric and thread structure parameters enables to predict the tear strength. He analyzed the geometry of tearing zone in the aspect of friction forces of stretched thread system (not torn) along the threads of perpendicular system (torn). Taylor didn’t analyze the phenomena taking place in perpendicular (torn) threads.

Research on the tearing process of trapezoidal samples was carried out by Hager, Gagliardi and Steele (Hager et al., 1947). They (as Taylor) did not take into consideration the influence of the perpendicular thread (torn) system and occurring friction forces in the torn system. Moreover, they assumed the linear relationship between the load and strain of stretched thread system.

Hamkins and Backer (Hamkins & Backer, 1980) presented their results concerning the tearing mechanics on the basis of two quite different in their structure fabrics: made from a glass yarn of „loose” weave and a big possibility of threads to be moved as well as from an elastomeric yarn of small possibility of threads to be moved. The application of previous models was not fully satisfactory for different variants of fabric structure.

Then the problem was analyzed by Seo (Scelzo et al., 1994a), who broaden the Taylor's (Taylor, 1959); (Letters to the Editor, 1974) model by the proposed by him parameters of the tearing zone geometry. The common feature of both models was an existence of such parameters as: the friction coefficient (thread by thread in a fabric), mean thread breaking force, distance between the axes of neighbor threads.

Scelzo, Backer and Boyce (Scelzo et al., 1994a); (Scelzo et al., 1994b) proposed the description of phenomenon taking place in the cotton fabric during the tearing basing on the tearing zone shape analysis and adapting the rheological model consisted of spring arrangement for a description of tearing process.

Now, the resistance on the static tearing is one of the most important assessment criteria of strength parameters of fabrics destined for the work and protective clothing, high-tech textiles, technical and interior textiles, upholstery and daily used clothing. In experiments the different specimen shapes are used, a choice of which can be found in the appropriate standards (Witkowska & Frydrych, 2004) (Witkowska & Frydrych, 2005).

In the chapter, there are presented the theory verified experimentally concerning the stages of the cotton fabric static tearing with taking into consideration the fabric tearing zone assessment, i.e., its length, depth and the thread number in the tearing zone. The analysis was carried out for the wing shape specimen described in the standard PN-EN ISO 13937-3:2002. An observation of tearing stages required the application of appropriate measurement system, which enabled the registration of changes taking place during the tearing process; and next, an analysis of obtained images. Such an opportunity was guaranteed by a specially elaborated for this purpose software working in the Windows environment. The whole software enables the observation of the video image on the computer screen, an image registration on CD with the given speed and image analysis. The special stand for the on-line tearing phenomenon registration was designed and built. Experiment was done for the model cotton fabrics of such a structure, which enables the observation of changes of tearing zone parameters dependably on the fabric weave at the assumption that the parameters of torn and stretched thread systems are unchanged.

1.1 Methods used for determination of static tear strength

In the whole period of fabric static tear resistance research, which has been estimated for over 95 years (Harrison, 1960), i.e., from 1915 up till now, there were proposed ca. ten different specimen shapes. Dependably on the assumed specimen shape, the particular investigators proposed their own specimen sizes and a measurement methodology, and also their own way of assessment of fabric tearing strength as well as own expression of results. The fabric tear strength (resistance) is a property determining the fabric strength on the static tearing action (static tearing), kinetic energy (dynamic tearing) and tearing on the "nail" of appropriate prepared specimen.

Different ways of tearing were reflected in the measurement methodology. The methods were diversified by the shape and size of specimen, a length of torn fabric distance, and also a way of tear force determination. The most popular methods were standardized. Now, in the all methods the parameter, which characterizes the fabric tear strength, is the tear force. In the static tearing methods as well as in the dynamic one the tearing process is a continuation of tearing started by an appropriate cutting the specimen before the measurement.

In Fig. 1, there are presented the specimen shapes, which are now used in the laboratory measurements of static tear strength; whereas in Table 1, there are presented the important data concerning the applied specimen shapes and dealt with them a measurement methodology.

Similarly as shapes and sizes of specimens also a way of tear force calculation has been changed since 95 years. This process was finished by a standardization, which unified a way of calculation of the static tear strength result. The result of static tearing can be read:

- directly from the measurement device;
- from the tearing chart dependably on the assumed measurement methodology.

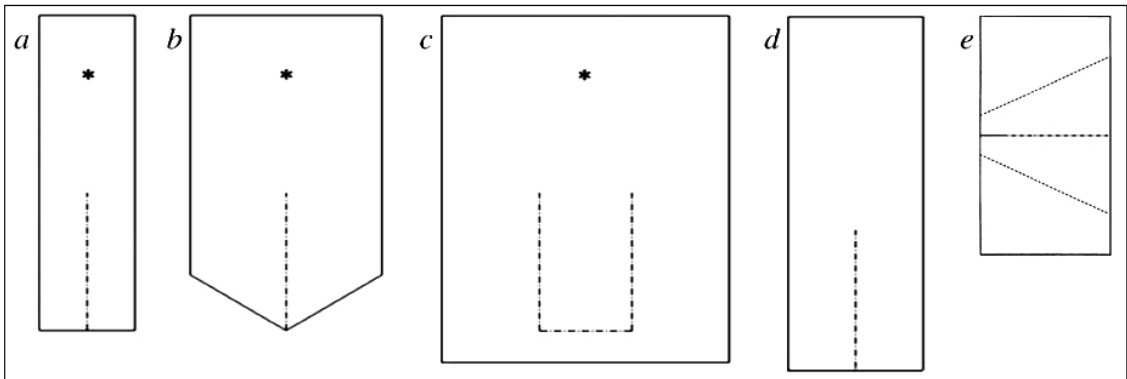


Fig. 1. The actual used shapes of specimens; a) trousers according to PN-EN ISO 13937-2 and PN-EN-ISO 4674-1-method B (for rubber or plastic-coated fabrics); b) wing according to PN-EN ISO 13937-3; c) tongue with double tearing according to PN-EN ISO 13937-4 and PN-EN ISO 4674-1-method A (for rubber or plastic-coated fabrics); d) tongue with single tearing according to ISO 4674:1977-method A1; e) trapezoidal shape according to PN-EN ISO 9073-4 (for nonwoven) and PN-EN 1875-3 (for rubber or plastic-coated fabrics)

A source: Own on the basis of present-day standards concerning the static tearing

Fig. 1a single tearing	Fig. 1b single tearing	Fig. 1c double tearing	Fig. 1d single tearing	Fig. 1e single tearing
Tearing direction to the acting force				
	⊥			⊥
Tearing distance, mm				
75	75	75	145	210
Measurement rate, mm/min				
100	100	100	100	100
Distance between jaws, mm				
100	100	100	75	25
Specimen dimension,mm; length, depth				
200; 50	200; 100	220, 150	225; 75	150; 75
Length of cut, mm				
100	100 ; angle 55°	100	80	15

Table 1. The description of static tearing methods

A source: Own on the basis of present-day standards concerning the static tearing

Now reading the tear forces from the tearing chart is possible for all used measurement methods of static tearing, i.e., for specimens of tongue shape with a single (trousers) and double tearing, for the wing and trapezoidal shape. As the tearing chart the curve, which occurs as a result of sample tearing on the tearing distance, is assumed. The initial point of tearing curve is a peak registered in the moment of breakage of the first thread (or thread group) being on the tearing distance, and the end of tearing curve is a breakage of the last thread (or thread group) on the given distance.

According to the standardized measurement procedure the following methods are used now:

- the method described in the standard series PN-EN ISO 13937 part 2 (trousers), part 3 (wind) and part 4: tongue – double tearing (Witkowska & Frydrych, 2004). The tearing graph is divided onto four equal parts starting from the first and finishing on the last peak on the tearing distance. The first part of graph is neglected in calculations. From the rest three parts of graph six the highest and lowest peaks are chosen (by the manual method) or all the peaks on 3/4 of tearing distance are calculated (by the electronic method). As a result an arithmetic mean of tear forces is given.
- the method A1 described in ISO 4674:1997, which is in agreement with the *American Federal Specifications* (Harrison, 1960), was elaborated in 1951. It relies on a median determination from five tear force values represented by maximum peaks for the medium graph distance creating 50% of tearing distance (Witkowska & Frydrych, 2004).
- the method described in PN-EN ISO 9073-4 for nonwovens and according to the PN-EN 1875-3 for rubber and plastic-coated fabrics - relies on the calculation of arithmetic mean from the registered maximum peaks on the assumed tearing distance.

1.2 Tear force as the criterion of fabric assessment

Analysis of fabric strength parameters showed that the tear strength is one of the important criteria of fabric assessment destined for the protective and work clothing; high-tech and technical textiles, interior textiles, upholstery and daily clothing.

There are many possibilities of fabric destruction by tearing. To the most characteristic cases of tearing belong:

- fabric tearing by nail or the other sharp tool;
- tearing in the places, where textile elements are joined together (in the utility or decorative purpose) by the elements of the high strength, for example rivets. In these places there can be often observed the characteristic tearing of its element from the fabric and the hole appearance;
- the hole occurrence (random) in the fabric by, for example, cigarette or spark. If this place is stressed, for example, during the utility, the local area decrement causes the increase of stresses on the hole circumference and the fabric is torn;
- fabric cutting on the same distance and next, its stretching. Such a situation is observed during the utility process, for example, cutting on the pocket can cause the clothing destruction, if these places are not protected at the ends.

The diversity of fabric tearing processes as well as the existence of many measurement methods often cause the problems dealt with a choice of the appropriate measurement method for the given fabric assortment. The selection of tearing strength measurement method for the given fabric should follow the analysis of criteria of such fabric assessment. These criteria are described in:

- harmonized standards (concerning the protective clothing);
- other standards (national, European, international);
- in so-called a list of technological and utilization indices (old Polish national standard introduced before 2000 year);
- contracts between textile producers and their customers.

Below, in Table 2, there is presented a division of static tear methods dependably on the chosen fabric assortment.

The other aspect is an application possibility of the admitted tearing method for the given fabric structure. It often happens that, for example, for a high tear strength fabric, i.e., of tear

force above 100 N or for fabric destined for the protective and work clothing (often cotton or cotton similar) of diversified tear strength dependably on the thread direction (warp-weft) and for fabric of weaves with long floating threads there is possible the application (undependably on the mentioned above rules) of only one tearing method, i.e., according to PN-EN ISO 13937 Part 3 (Fig. 1c). It is caused by the fact that the sample shape in this method and a way of mounting it in the tensile tester jaws enables the obtaining the better its clamping in the tensile tester jaws. Thanks to it the sample is not broken in the jaws and the measurement can be performed.

Textiles - rubber or plastic-coated fabric	
PN-EN 1875	Technical textiles
ISO 4674:1977	Method A1: protective clothing (high-visibility warning for professional use; protection against rain), Method A2: textiles for tarpaulin
PN-EN ISO 4647-1	Method A: Protective clothing (protection against cold), Method B: protective clothing (for firefighters for firefighting)
Textiles - non-coated	
PN-EN ISO 13937-2	protective clothing (for firefighters in action), work clothing (overalls, shirts, trousers), mattress – woven, daily textiles, textiles for flags, banners
PN-EN ISO 13937-3	upholstery (furniture) textiles, bed clothing, textiles for beach chairs, technical textiles (roller bind)
PN-EN ISO 13937-4	work clothing (changeable with PN-EN ISO 13937-2)

Table 2. The division of static tear methods dependably on the chosen fabric assortment
A source: Own on the basis of present-day standards concerning the static tearing

Summing up, the significance of static tear force measurement increased in the last years. Laboratory practice showed that this parameter has the same importance for the fabric assessment as a tensile strength. The main reason of such situation is the growing significance of safe fabric utility, first of all destined for the protective clothing. It should be pointed out that the fabric producers taking into consideration the significance of strength parameters in the complex fabric assessment apply modern raw materials of better quality, for example, PES, PA, PI, AR and their blends with natural fibers, which guarantee the obtaining the required level of these parameters. The fabric tear strength is the complex problem, character of which is still not fully explained. The big number of tearing methods and not useful models with parameters, which are not available in the laboratory practice make difficult the prognosing the tear strength; therefore, the experimental research in this field has been necessary.

2. Analysis of stages of cotton fabric static tearing process for the wing shape specimen

The tearing process of cotton fabric sample of the wing shape (according to PN-EN ISO 13937-3) started by loading the specimen by the tensile force was divided into three stages, which were presented schematically in Fig. 2.

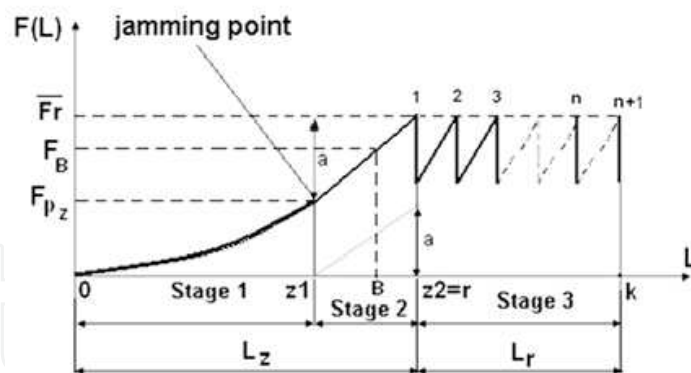


Fig. 2. The graph of tear force of specimen in the function of tensile tester clamp displacement, i.e., the tearing process graph. Stages of tearing process of cotton fabric for the wing shape specimen

Source: own

In Fig. 2 the following designations were assumed:

point 0 - start of sample tearing process, i.e., start of movement of tensile tester clamp. *Point 0* means also the beginning of stage of both thread system displacement;

point z1 - the end of stage of thread displacement and the beginning of stretching the torn thread system;

point z2 - the end of stretching stage and the beginning of thread breakage - *point r*;

point k - the end of specimen tearing process, i.e., the end of measurement;

point B - any point on the distance $z1-z2$;

distance a - the value of breaking force, i.e., the value, which is „added“ to the value of displacement in the moment of achieving the jamming point;

L - the way of movement of the tensile tester clamp;

L_z - the way of the movement of the tensile tester clamp up to the first thread breakage on the distance L_r ;

L_r - tearing distance, i.e., the distance of displacement of tensile tester clamp since the moment of first thread breakage up to the breakage of the last thread on the marked tearing distance;

$F(L)$ - the stretching force acting on the torn sample on the distance of displacement of tensile tester clamp;

$\overline{F_r}$ - the mean value of tearing force calculated as an arithmetic mean of local tear forces represented by peaks 1, 2, 3 ... n, n+1 on the tearing distance L_r , (for ideal conditions $F_{r1}=F_{r2}=F_{r3}=F_{rn}=F_{rn+1}$);

F_B - the value of tensile force in any point B;

Line z1 - the end of distance a - the relationship between the breaking force and strain for the single thread, i.e., $W_z = f(\epsilon_z)$;

Curve 0 - jamming point - the relationship between the distance, on which the clamp of tensile tester is moving and the force causing the displacement of both thread systems of torn specimen up to achieving the thread jamming point;

Curve 0-1 - the relationship between the distance, on which the clamp of tensile tester is moving and the stretching force up to the first thread breakage on the tearing distance.

Curve 0-1 on the distance $z1-z2$ is the value of line *z1* - the end of a distance - moved about a displacement force value in the jamming point.

The analysis of tearing stages is presented assuming that the process of forming the fabric tearing zone on the assumed tearing distance has been started since the moment that the tensile tester clamp has started to move. In the tearing zone dependably on the stage of tearing the following areas can be distinguished: displacement, stretching and breaking (Witkowska, 2008).

Stage 1. Mutual displacement of both specimen system threads. The appearance of the *displacement area in the tearing zone*. The phenomena taking place in this stage are initiated in the moment of starting the movement of tensile tester clamp. The clamp movement on the *distance 0-z1* (Fig. 2) causes the displacement of both thread systems of torn fabric specimen, i.e., threads of stretching system - mounted in the clamps and threads of torn system - perpendicular to the thread system mounted in the clamps. It was assumed that in this stage the threads of torn system are not deformed.

Stage 2. Stretching the threads of torn system. It is done due to the further increase of loading the threads of stretched system, but without the mutual displacement of both thread systems of torn fabric sample. In this stage there are *two areas of tearing zone: displacement and stretching*. Continued in this stage the movement of tensile tester clamp on the *distance z1-z2* (Fig. 2) causes that due to a lack of possibility of further mutual displacement of both fabric system threads the first thread of torn system (being in the displacement area) goes into the stretching area and started to elongate up to the achievement of critical value of elongation, i.e., the value of elongation at the given thread breaking force. Therefore, it was assumed that in the successive tearing process moments in the stretching area there was only one thread of torn system, for which the relationship between the load and strain was linear.

Stage 3. The breakage of torn system thread on the assumed tearing distance. In this stage of tearing process the tearing zone is *built from three areas: displacement, stretching and breaking*. The further movement of tensile tester clamp on the *distance r-k* (Fig. 2) causes the breakage of successive threads of torn system on the tearing distance up to finishing the tearing process (*point k*, Fig. 2).

Between stages 1 and 2 there is so-called the *jamming point* (Fig. 2), i.e., the point, in which fabric parameters and values of friction force between both system threads make impossible the further mutual displacement of both thread systems. Therefore, the achievement of jamming point finishes the stage 1, and the breakage of the first thread on the given tearing distance finishes the stage 2.

Since the moment of the first thread breakage on the tearing distance, the phenomena described in *stages 1, 2 and 3* have been taking place simultaneously up to the moment of breakage of the last thread of torn system on the tearing distance.

The characteristics of tearing process stages have some features similar to the description of this phenomenon for the wing shape specimen presented by the previous researchers of tearing process, i.e.:

1. Distinguishing in the torn fabric sample two thread systems, i.e., the stretched thread system - mounted in the tensile tester clamps; and the torn thread system, which is perpendicular to the stretched one (Krook & Fox, 1945); (Scelzo et al., 1994a); (Scelzo et al., 1994b); (Teixeira et al., 1955); (Taylor, 1959). Both systems can be called also un-torn and torn.
2. Distinguishing the fabric tearing zone (Krook & Fox, 1945); (Scelzo et al., 1994a); (Scelzo et al., 1994b); (Teixeira et al., 1955); (Taylor, 1959) in the torn wing shape specimen.
3. Stating that in the torn fabric sample there are simultaneously the displacement and stretching of both system threads, displacement of stretched system of threads (Taylor, 1959), displacement of both thread systems (Teixeira et al., 1955).

4. Limiting the fabric tearing process to three components represented by threads being in the tearing zone (Scelzo et al., 1994a) (Scelzo et al., 1994b) (Teixeira et al., 1955): the first component - torn system thread in the position "just before the breakage", second and third components - "at the border of tearing zone" threads of stretched system (threads on the inner edge of cut sample elements).

To the most important differences between the descriptions of fabric tearing process presented in this paper and done by the previous Authors belong:

1. Division of fabric tearing zone onto the following areas: the displacement, stretching and breaking.
2. Distinguishing the jamming point of both thread systems of torn sample.
3. Stating that the both thread system displacement (*stage 1*) phenomenon and stretching (*stage 2*) of torn thread system are not taking place at the same time. This statement is true at the assumption that it is possible to find such a point, in which the first thread of torn system being in the displacement area cannot be further displaced. This thread goes into the stretching area and starts to elongate up to achieving the critical value of elongation and the thread breakage.
4. Stating that the tear force is a sum of vector forces, i.e., the force, which causes the displacement without both system thread deformation up to achieving the so-called jamming point; and the force, which causes the elongation of torn system thread up to achieving the critical value of elongation and thread breakage.

Consideration that assumptions for elaboration of the theoretical model of cotton fabric tearing for the wing shape sample are proceeded by the separation of three tearing stages in the fabric tearing zone, i.e., displacement of both system threads to achieve the thread jamming point, stretching and breaking the threads of torn system. Next, there was stated that from the moment of the first thread breakage on the tearing distance the phenomena described in the mentioned above stages have a place simultaneously up to the breakage of the last thread of torn system. The force put to the torn specimen in the function of displacement of tensile tester clamp, i.e., $F=f(L)$ was described as follows:

$$F=f(L)=F_p(L)+Fw_z(L) \quad (1)$$

where:

$F_p(L)$ - force F in the function of displacement of tensile tester moving clamp during the displacement of both system threads of torn sample;

$Fw_z(L)$ - force F in the function of displacement of tensile tester moving clamp during the stretching one thread of torn system, which is in the tearing zone at this moment. It was assumed that the relationship $Fw_z(L)$ is described by the Hookean law.

According to the proposed stages of tearing process the relationship (1) takes the form:

$$\text{stage 1: } F=f(L)=F_p(L) \quad (2)$$

$$\text{stage 2 and stage 3: } F=f(L)=F_p(L)+Fw_z(L) \quad (3)$$

and the thread breakage in the tearing zone:

$$F=f(L)=F_r \quad (4)$$

where:

F_r - local value of breaking force.

The value of fabric breaking force in the moment of the first thread breakage on the given tearing distance on the border of stretching and breaking of tearing zone is described by the relationship (5) (general model of fabric tearing):

$$F_r = F_p(z_1) + F_{w_z}(r) = F_{pz1} + F_w \quad (5)$$

where:

r - the end of stages of stretching of torn thread system and the beginning of thread breaking stage;

F_{pz1} - the value of displacement force in the jamming point of both thread systems of torn fabric sample;

F_{w_z} - the value of breaking force of torn thread system.

3. Experiment

3.1 The stand for image analysis

The stand for image analysis was built from the following elements: the tensile tester Zwick model 1120 (1), jaws of tensile tester (2), computer with the software *test-Xpert* (3) for textile static tearing, color camera TV (5) (zoom 3.5 to 8.0 mm), computer with the software *Microstudio* (4) or image analysis, tripod camera (6) (Witkowska & Frydrych, 2008); (Witkowska, 2008). In order to observe the cotton fabric tearing stages and tearing zone the video system was used (Fig. 3 and Fig. 4).

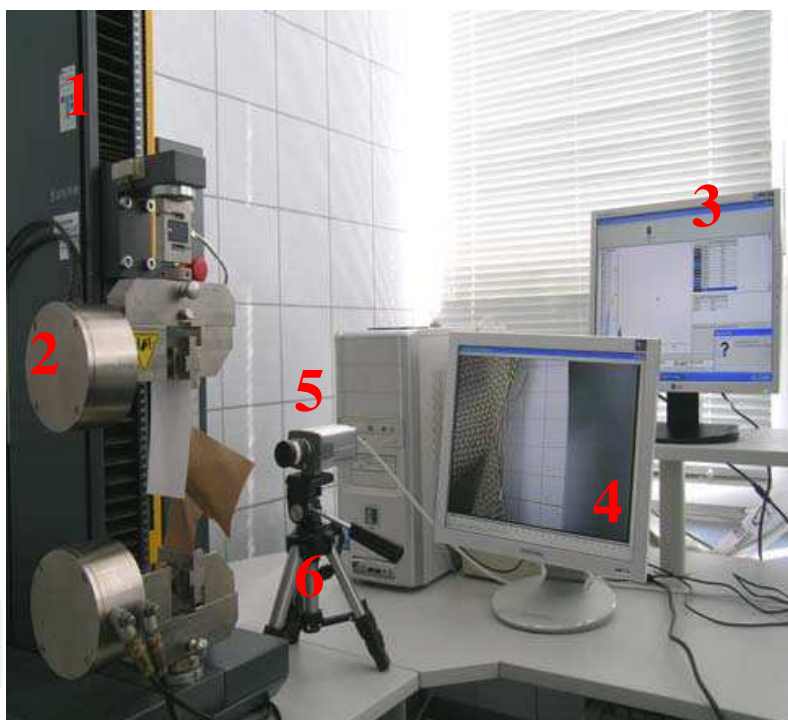


Fig. 3. Stand for the registration of tearing process and computer analysis of images of tearing zone

Source: own

The system enables also to archive and analyze the static images. To obtain a dynamic image the stand assured the registration of 25 images per second. For the image acquisition there was used the digital camera CCD CP-720 with a special optical system enabling the analysis of moving images, choosing the observed area and obtaining the clear (sharp) images of analyzed objects. In order to archive and analyze the static images the *MicroStudio Video* software was applied. From the video images showing the fabric tearing there were chosen

the static images representing the fabric in the exactly the same measurement points. On the basis of static images there were determined the length of tearing zone (l_{Δ}), depth of tearing zone (d_{Δ}), and the thread number in the tearing zone ($L_{n-\Delta}$) for each marked measurement point. An analysis of static images representing tearing zones enables to state that the tearing zone in many cases is not symmetrical according to $x-x$ axis going through the point determining the depth of tearing zone. Therefore, the length of distance from the $x-x$ axis to the end of marked tearing zone is ($l_{\Delta\uparrow}$), the length (l_{Δ}) and depth (d_{Δ}) of tearing zone were assumed in the agreement with Teixeira's (Teixeira et al., 1955) model of tearing zone. From the static images the following values were read: the total tearing zone length (l_{Δ}), length ($l_{\Delta\uparrow}$) and depth (d_{Δ}) of tearing zone in pixels; and next, these values were recalculated into millimeters.



Fig. 4. The way of sample mounting in the tensile machine jaws for the tearing zone registration
Source: own

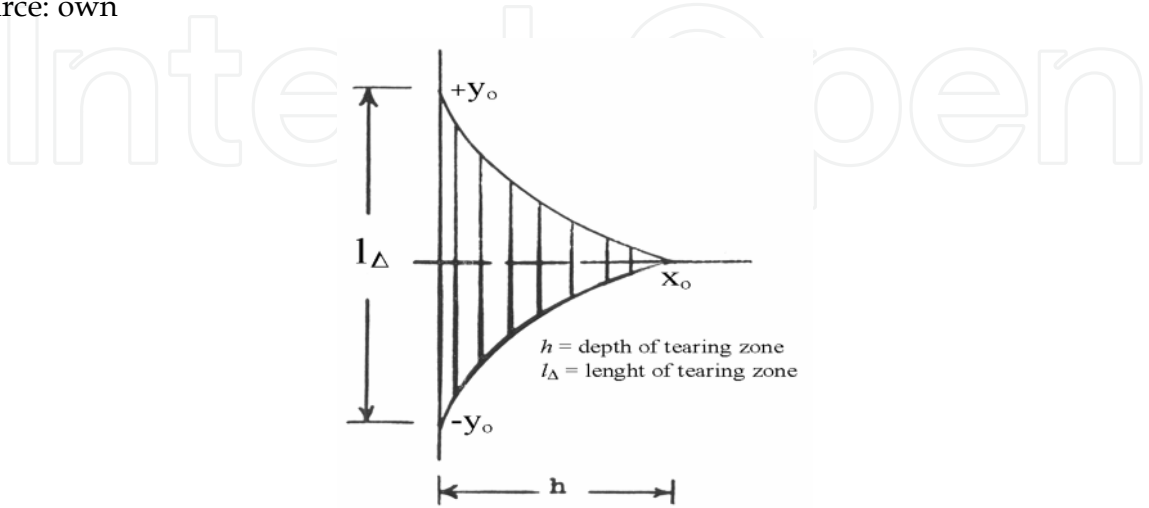


Fig. 5. Teixeira's model of fabric tearing zone (Teixeira et al., 1955)

Successive operations at registration of tearing process of cotton fabrics:

1. Mounting the marked specimen of wing shape in the tensile machine jaws.
2. Setting the video camera in such a position to have on the screen of computer with *MicroStudio Video* software the specimen with the marked measurement points and appropriate scale (millimeter paper).
3. Simultaneous starting of tensile machine and software *MicroStudio Video* registering the video camera image.
4. Finishing the movement registration and the specimen tearing process after the third measurement point.
5. Repeating the points 1 to 4 for each prepared specimen.

3.2 Testing materials

100% cotton woven fabrics of characteristics presented below from woven color threads were design and manufactured for the need of experiment. An application of color threads facilitated the observation of video images of the fabric tearing process.

Fabric characteristics (Witkowska, 2008):

- weaves: plain, twill 3/1 Z, satin 7/1 (5), and broken twill 2/2 V4;
- warp and weft thread linear density: 25 tex x 2;
- the mean number of threads per 1 dm: warp - 188, weft - 174.

From the each fabric three specimens in each direction (warp/weft) were cut. On the right side of fabric starting from the cut edge three points were marked every 5 mm representing three measurement distances, i.e., 5 mm, 10 mm and 15 mm (Fig. 6). The speed of testing was 75 mm/min.

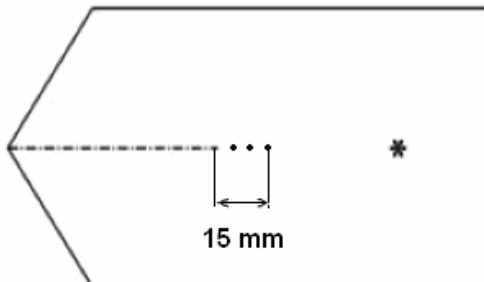


Fig. 6. The way of sample marking for the measurement
Source: own

The static tear resistance of analyzed fabrics was determined according to PN-EN ISO 13937-3:2002. From each fabric 10 specimens in the warp and weft directions were measured; and next, the tear force values using the tensile tester Zwick 1120 controlled by the software *test-Xpert version 4.12* were determined. The measurement was carried out with the speed 100 mm/min. From charts the tear force (F_t) for the whole tearing distance, i.e., from the first to the last peak registered on the assumed tearing distance were read. The obtained values of force of 10 specimens were statistically assessed; the mean value and variation coefficient were determined.

3.3 Results

The set of mean values of cotton fabric tear forces dependably on the weave of analyzed fabrics are presented in Table 3. The data of obtained parameters of tearing zone

dependably on the fabric weave, length of tearing distance are presented in Tables 4÷7; whereas the chosen static images of cotton fabrics tearing zones of registered in the measurements point 15 mm (specimen 1) for the wing shape specimens in plain and satin weave variants are presented in Fig. 7 and 8.

Parameter/fabric	Fabric weave							
	plain		twill 3/1 Z		satin 7/1 (5)		broken twill 2/2 V4	
	warp	weft	warp	weft	warp	weft	warp	weft
Mean tear force, N	19.7	19.8	23.9	23.0	63.2	52.2	26.5	21.0
Variation coefficient, %	3.6	3.7	3.8	3.7	4.4	5.4	1.4	5.1

Table 3. The set of tear force results for cotton fabrics dependably on the weave

Specimen	Plain warp - measurement point											
	5 mm				10 mm				15 mm			
	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$
1	7.0	3.5	0.7	1	4.5	2.1	0.7	2	5.7	2.8	0.7	2
2	7.2	3.6	0.7	2	4.8	2.3	0.8	1	6.3	3.1	0.7	2
3	7.7	3.9	1.0	2	5.0	2.4	0.8	2	6.5	3.3	1.0	2
Specimen	Plain weft - measurement point											
	5 mm				10 mm				15 mm			
	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$
1	5.2	2.6	0.5	1	4.6	2.3	1.0	1	5.2	2.6	1.0	1
2	5.5	2.7	1.0	1	4.7	2.3	0.9	2	5.1	2.5	0.8	1
3	5.1	2.5	0.8	1	5.6	2.8	1.0	1	5.2	2.6	0.9	1

Table 4. Parameters of tearing zone and the thread number in the tearing zone for the model plain cotton fabrics

Specimen	Twill 3/1(Z) warp - measurement point											
	5 mm				10 mm				15 mm			
	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$
1	18.7	9.3	2.5	5	24.7	12.3	3.6	5	31.9	15.4	4.8	6
2	18.7	9.4	2.6	4	28.3	14.2	4.1	5	36.5	18.6	5.3	7
3	18.7	9.4	2.6	5	26.1	13.0	3.2	5	35.0	15.6	5.0	7
Specimen	Twill 3/1(Z) weft - measurement point											
	5 mm				10 mm				15 mm			
	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$	l_{Δ}	$l_{\Delta\uparrow}$	d_{Δ}	$L_{n-\Delta}$
1	13.1	6.3	2.1	5	25.9	13.0	3.6	6	32.9	14.7	5.2	8
2	12.2	5.9	2.1	4	25.8	12.8	3.8	5	31.1	14.9	5.4	8
3	13.1	6.6	2.4	3	24.3	12.2	4.1	5	34.3	16.4	5.2	7

Table 5. Parameters of tearing zone and the thread number in the tearing zone for the model twill 3/1 Z cotton fabrics

Specimen	Satin 7/1 (5) warp - measurement point											
	5 mm				10 mm				15 mm			
	l_A	$l_{A\uparrow}$	d_A	L_{n-A}	l_A	$l_{A\uparrow}$	d_A	L_{n-A}	l_A	$l_{A\uparrow}$	d_A	L_{n-A}
1	12.1	6.0	2.9	7	22.3	11.1	4.1	10	41.5	21.2	5.6	14
2	13.7	7.7	2.9	7	24.9	12.2	3.5	9	39.8	18.2	5.7	12
3	13.6	6.9	3.0	5	24.4	14.2	3.6	8	40.3	24.0	5.2	11
Specimen	Satin 7/1 (5) weft - measurement point											
	5 mm				10 mm				15 mm			
	l_A	$l_{A\uparrow}$	d_A	L_{n-A}	l_A	$l_{A\uparrow}$	d_A	L_{n-A}	l_A	$l_{A\uparrow}$	d_A	L_{n-A}
1	13.1	7.1	2.5	6	24.5	12.1	3.1	9	34.5	13.5	4.6	14
2	14.0	7.0	2.4	7	25.0	12.4	3.8	10	34.4	15.1	4.6	15
3	12.7	6.2	2.3	6	26.1	13.1	3.8	13	34.0	17.2	4.9	17

Table 6. Parameters of tearing zone and the thread number in the tearing zone for the model satin 7/1(5) cotton fabrics

Specimen	Broken twill 2/2 V4 warp - measurement point											
	5 mm				10 mm				15 mm			
	l_A	$l_{A\uparrow}$	d_A	L_{n-A}	l_A	$l_{A\uparrow}$	d_A	L_{n-A}	l_A	$l_{A\uparrow}$	d_A	L_{n-A}
1	14.5	7.2	2.3	5	23.9	12.0	4.2	7	34.3	15.9	5.1	10
2	15.7	7.8	2.2	5	24.1	9.0	3.6	6	35.5	12.7	5.5	9
3	16.0	7.0	2.4	4	25.4	12.6	4.0	7	38.5	18.6	5.6	10
Specimen	Broken twill 2/2 V4 weft - measurement point											
	5 mm				10 mm				15 mm			
	l_A	$l_{A\uparrow}$	d_A	L_{n-A}	l_A	$l_{A\uparrow}$	d_A	L_{n-A}	l_A	$l_{A\uparrow}$	d_A	L_{n-A}
1	14.8	7.5	2.0	4	22.8	11.5	3.6	7	34.3	17.2	4.3	10
2	14.3	7.1	1.6	4	23.9	12.0	3.7	9	35.2	16.7	5.0	13
3	13.4	6.8	2.0	4	24.9	12.5	3.3	7	34.4	16.7	4.9	11

Table 7. Parameters of tearing zone and the thread number in the tearing zone for the model broken twill 2/2 V4 cotton fabrics

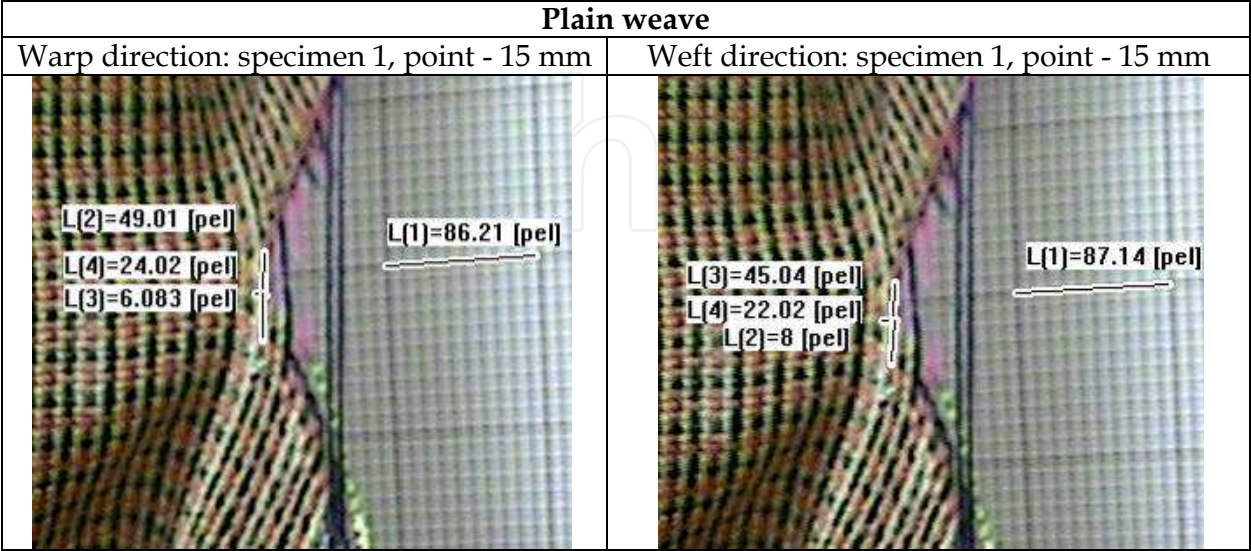


Fig. 7. The fabric images of tearing zone registered in the measurement point 15 mm for the wing shape specimen for plain weave

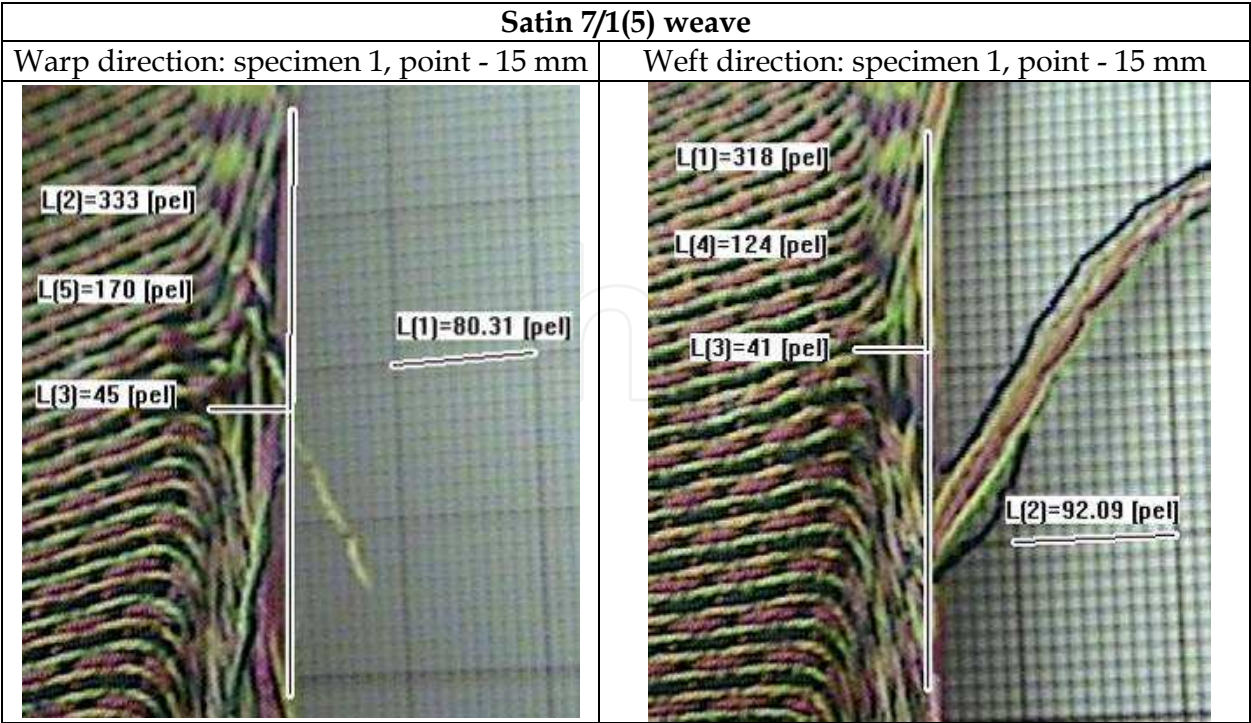


Fig. 8. The fabric images of tearing zone registered in the measurement point 15 mm for the wing shape specimen for satin 7/1(5) weave

4. Analysis and modelling the fabric tearing zone geometry

4.1 Analysis of fabric tearing zone geometry parameters

The graphic presentation of obtained results of the thread number in the tearing zone as well as the mean values of length and depth of zone dependably on the fabric weave, the torn arrangement (warp/weft) and tearing distance are shown in Fig. 9, 10 and 11.

The analysis of presented photos allows drawing out the following conclusions:

1. The smallest changes and at the same time the lowest values of length and depth of tearing zone as well as the thread number in the tearing zone dependably on the tearing distance were observed for zones registered for plain fabrics. The torn thread system (warp/weft) does not influence significantly the changes of mentioned parameters. An analysis of movies presenting the plain fabric tearing showed that in the assumed in measurements the maximum specimen length distance 15 mm there are many zones, in which there are the most often one thread. When it is broken, the next tearing zone is started to create. The threads in the plain fabric are displaced insignificantly. It is worth to remind (Tab. 3) that the obtained mean values of tear forces for plain cotton fabrics are on the lowest level in the comparison to the rest fabrics of different weaves.

The obtained values of plain cotton fabric tear resistance and carried out observations of tearing zones confirmed the Teixeira's et al. (Teixeira et al., 1955), Hamkins's and Backer's (Hamkins & Backer, 1980) also Scelzo, Backer's, Boyce's (Scelzo et al., 1994b) conclusions that for fabrics of higher number of interlacements (on the assumed tearing distance) the value of tear force and also of tearing zone parameters are the lowest ones.

In Fig. 12, there are shown the torn (on the distance of 15 mm) plain cotton fabric specimens. In the place of tearing the sample deformation is not observed, the successive threads on the tearing distance are broken.

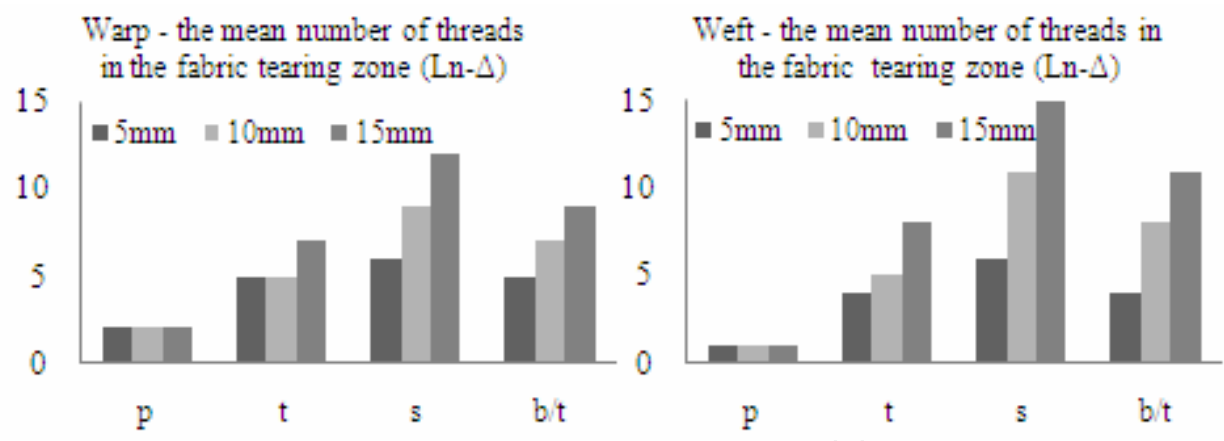


Fig. 9. The mean number of threads in the cotton fabric tearing zone ($L_{n\Delta}$) dependably on the weave, torn thread system (warp/weft) and the tearing distance

where: p, t, s, b/t are symbols of cotton fabric: plain, twill 3/1 (Z), satin 7/1 (5), broken twill 2/2 V4;
 $L_{n-\Delta}$ is the mean thread number in the fabric tearing zone;
5, 10, 15 are symbols of specimen measurement points successively on 5-th, 10-th and 15-th millimeter of tearing distance.

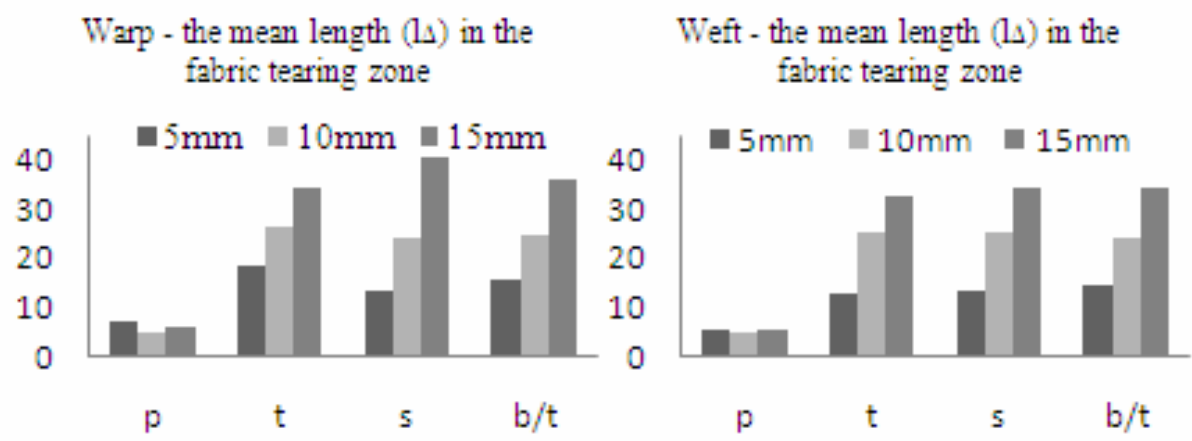


Fig. 10. The mean length (l_{Δ}) of tearing zone dependably on the fabric weave, torn thread system (warp/weft) and the length of tearing distance

where: p, t, s, b/t are symbols of cotton fabric: plain, twill 3/1 (Z), satin 7/1 (5), broken twill 2/2 V4,
 l_{Δ} is the mean length of tearing zone, in mm,
5, 10, 15 are symbols of specimen measurement points successively on 5-th, 10-th and 15-th millimeter of tearing distance.

2. Mean values of length and depth of tearing zones registered for twill 3/1 Z, satin 7/1 (5) and broken twill 2/2 V4 fabrics increase in the torn thread system with the increase of tearing distance. But in the area of given measurement points (5, 10, 15 mm) these lengths are smaller dependably on the weave change and these changes concern the mean tearing zone length. The observation of images of specimen tearing allow stating that the increase of

length and depth of tearing zone of mentioned weaves is caused by the graduated process of zone formation, i.e., in the last measurement point (15 mm). Such a way of tearing zone formation results from the bigger possibility of thread displacement in fabrics of weaves with the smaller number of interlacements (Fig. 10 and 11) than the plain weave has.

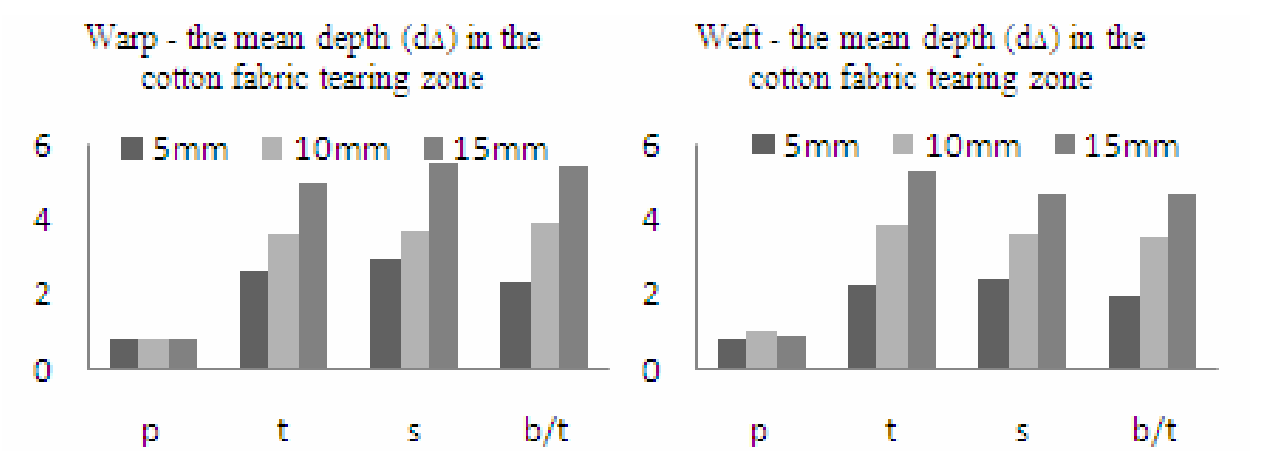


Fig. 11. The mean depth (d_{Δ}) of tearing zone dependably on the fabric weave, torn thread system (warp/weft)) and the length of tearing distance

where: $p, t, s, b/t$ are symbols of cotton fabric: plain, twill 3/1 (Z), satin 7/1 (5), broken twill 2/2 V4,
 d_{Δ} is the mean of depth of tearing zone, in mm,
5, 10, 15 are symbols of specimen measurement points successively on 5-th, 10-th and 15-th millimeter of tearing distance.

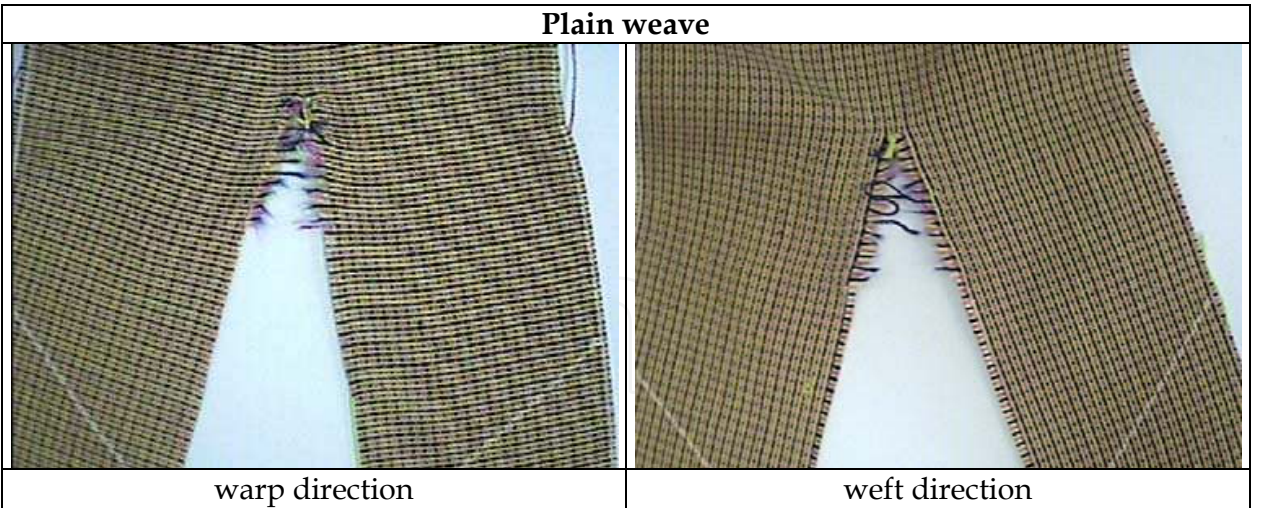


Fig. 12. The wing shape specimens of plain fabrics torn on the measurement distance 15 mm
Source: own

3. The analysis of results of mean tear force of fabrics of proposed weaves showed that in the warp as well as weft direction the highest mean values of tear resistance were obtained for fabric of satin 7/1 (5) weave. But the mean values of length and depth of tearing zone for fabric samples of this weave in the given measurement point only in two cases, i.e., warp system – measurement point 15 mm, and weft system – measurement point 10 mm (Fig. 10

and 11) are a little higher than analogous values for twill and broken twill samples. It can be explain in the following way:

3.1 Observation of graphs $F_r=f(L_r)$ (Fig. 13).

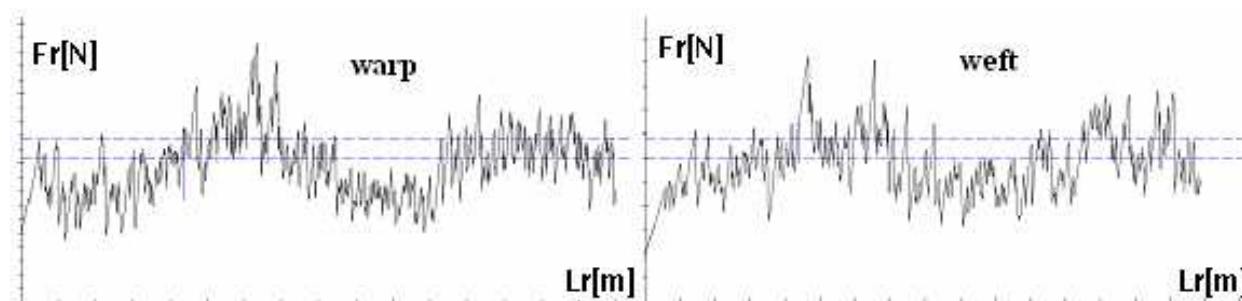


Fig. 13. The example of cotton fabric of satin 7/1 (5) weave tearing process graphs

Source: own

The local values of tear forces (F_r) of satin 7/1 (5) fabric registered on the tear distance (L_r), are characterized by a big variability. Moreover, the highest values of local tear forces are observed the most often from the tearing distance about $\frac{1}{4}$ of chart, i.e., about 40 mm. Therefore, the highest local values of tear forces, and at the same time - the highest values of length and depth of tearing zone are observed in the assumed observation points (5, 10, 15 mm).

3.2 Observation of torn fabric samples of the following weaves: twill 3/1 Z, satin 7/1 (5) and broken twill 2/2 V4 (Fig. 14).

Analyzing the obtained images it can be noticed a strong deformation of torn fabric specimens of mentioned weaves – the bigger than in the case of deformation of plain fabric sample. Particularly visible it is for satin fabric samples 7/1(5). The successive threads on the tearing distance are not broken, they are only „pulled out” from the fabric sample (from many of them totally). It is caused by a fact that threads of fabric of this weave have a big possibility of displacement and it is difficult to achieve the so called „jamming point” (the point, in which fabric parameters and values of friction forces between threads of both systems enable the further mutual thread displacement in the torn samples. The force, which is necessary to pull out the single thread and in the further part of specimen the group of threads, is higher than the force necessary for breaking threads. From one side it explains very high tear resistance values for satin fabrics; and from the second one – it explains the variability of local tear forces on the tearing distance. The variability of local values of tear forces results from the variable number of pulled out threads from the fabric on the tearing distance. At the beginning of tearing process the number of pulled out threads increases, what causes the growth of local values of tear forces. If the tearing is continued, the first thread or a few first threads being on the tearing distance are pulled out from the fabric and the local values of tear forces will be lower. Next, on the tearing distance there are appeared the successive threads, which gradually are pulled out from the fabric and the local values of tear forces again start to rise. This process is repeated up to the end of tearing distance.

The described sample deformation during the tearing process is also observed, but in the lower extent in the twill and broken twill fabric samples. In the torn samples of mentioned weaves on the tearing distance there are visible the broken as well as „pulled out” from the fabric threads.

4. The highest number of threads in the tearing zone in the each measurement point as well as in the torn thread system (warp/weft) were observed for satin 7/1 (5) (Fig. 9).

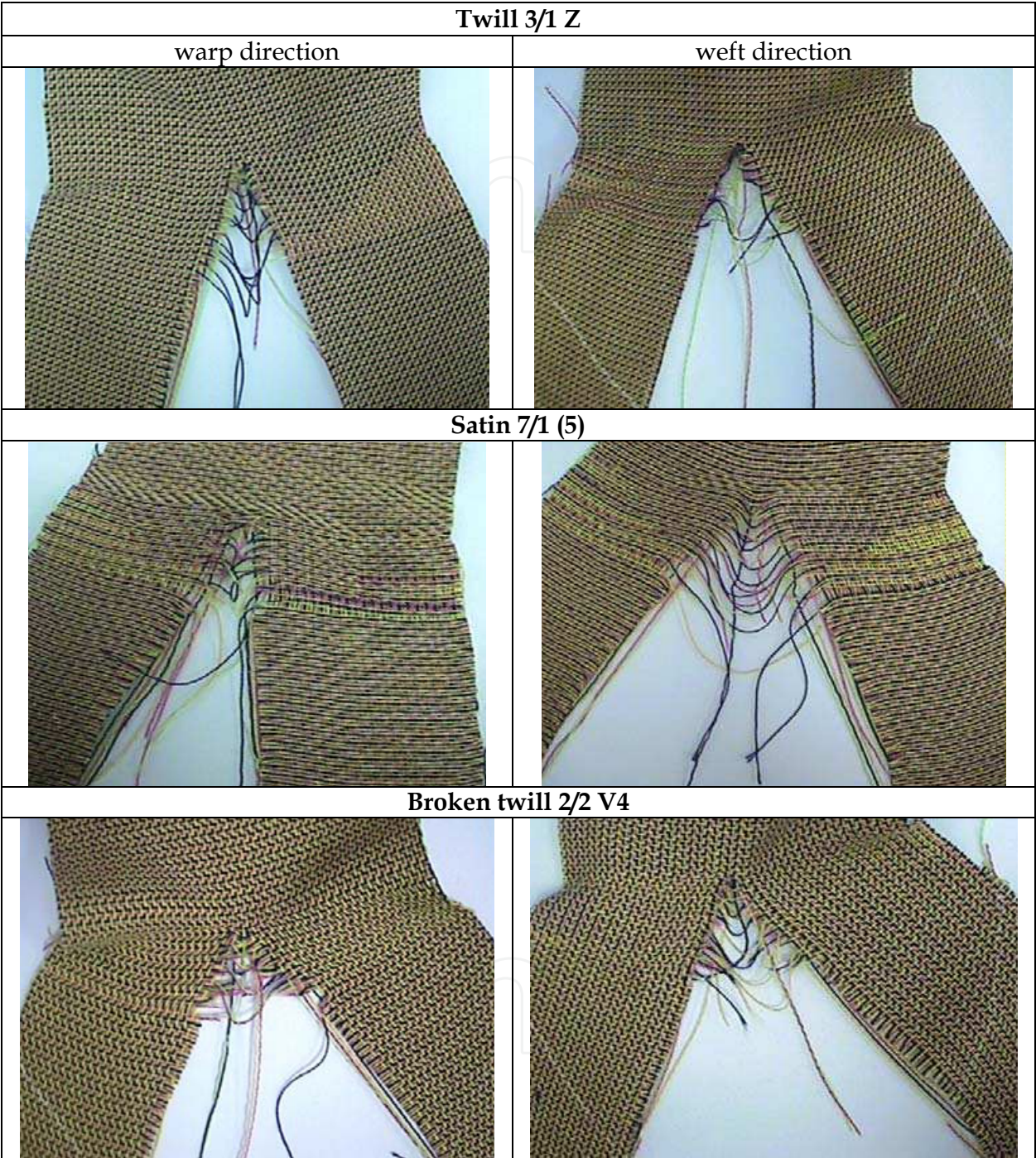


Fig. 14. The wing shape specimens of twill 3/1 Z, satin 7/1(5) and broken twill 2/2 V4 fabrics torn on the measurement distance 15 mm
Source: own

4.2 Modelling the shape of „arms” of tearing zone

In this chapter the process of modelling the shape of tearing zone was divided into two stages. In the first one in order to make a better visualization of sizes and to compare the

tearing zones of samples of four weaves in Fig. 15, there were set in the same scale the obtained values of parameter of fabric tearing zone for all the registered zones. The marked on the axes points, i.e., the depth of tearing zone d_{Δ} , length of tearing zone $l_{\Delta\uparrow}$ [length $l_{\Delta\uparrow}$ is the length measured from the abscissa $x-x$ (axis going through the point determining the depth of tearing zone) up to the end of the marked length of tearing zone l_{Δ}] and the length difference $l_{\Delta}-l_{\Delta\uparrow}$ were connected by the straight lines.

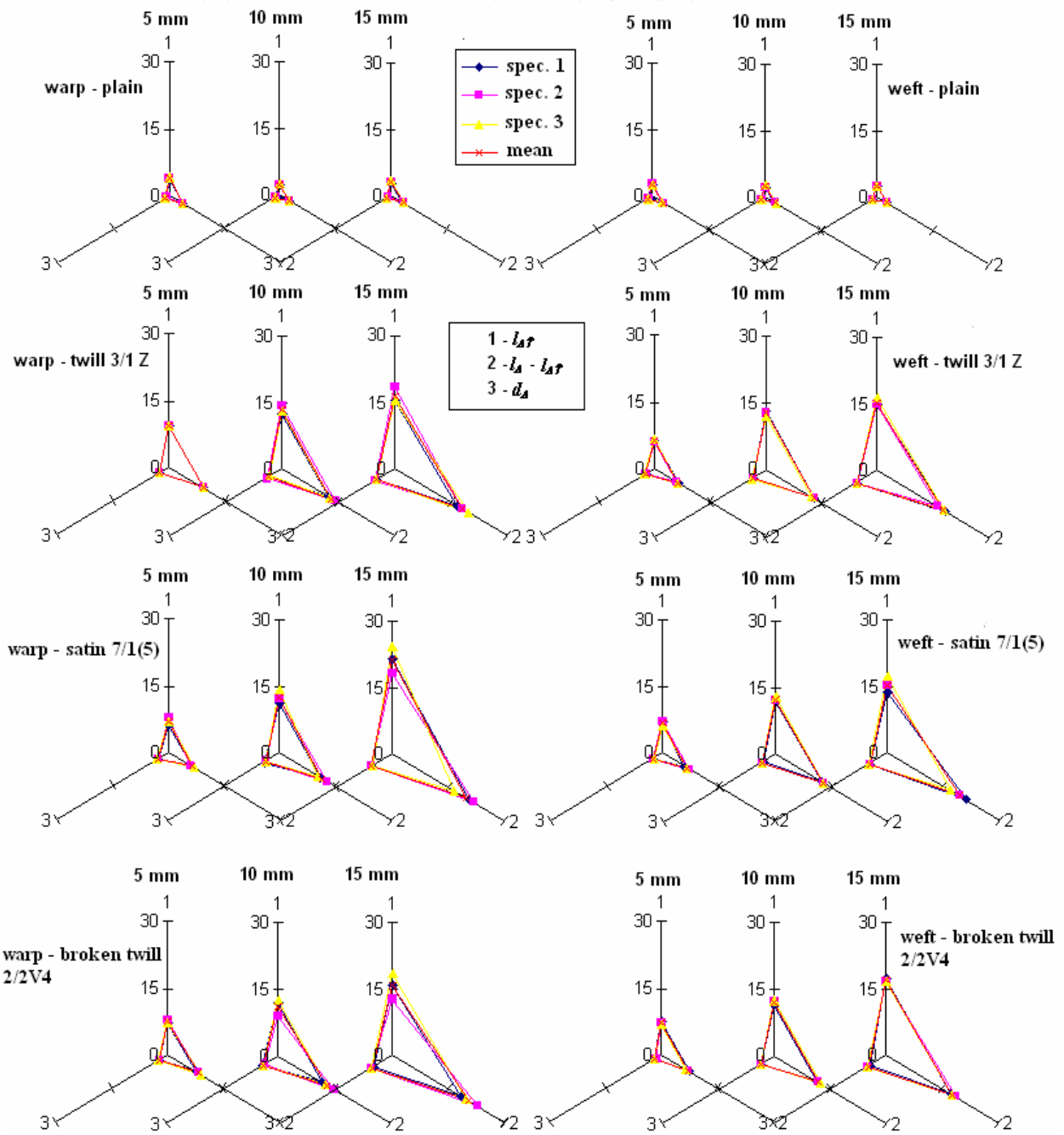


Fig. 15. The size of fabric tearing zone dependably on the fabric weave, torn thread system (warp/weft) and measurement point

The schematic presentation of fabric tearing zones enabled to notice the following observation:

- disproportions between the size of tearing zones dependably on the torn fabric weave;
- insignificant differences between the sizes of tearing zones in the given weave dependably on the given thread system (warp/weft);
- small variability of obtained length and depth for three specimens measured in the thread system (warp/weft);
- symmetry of tearing zone ($l_{\Delta}-l_{\Delta\uparrow} = \frac{1}{2} l_{\Delta}$) according to abscissa $x-x$ going through the point determining the zone depth for torn fabric specimens of the following weaves:
 - plain in the all measurement points for the thread system (warp/weft);
 - twill 3/1 Z for the measurement points (5 and 10 mm) for the thread system (warp/weft);
 - broken twill 2/2 V4 for the measurement point 5 mm for the weft direction;
- a lack of symmetry of tearing zone ($l_{\Delta}-l_{\Delta\uparrow} \neq \frac{1}{2}l_{\Delta}$) in the relation to the abscissa $x-x$ for the rest variants of torn specimens. The biggest differences between the values $l_{\Delta\uparrow}$ and $\frac{1}{2}l_{\Delta}$, i.e., differences ≥ 1 mm were calculated for the tearing zones of fabrics of the following weave:
 - satin 7/1 (5): warp thread system – measurement point (10 and 15 mm), weft thread system – measurement point 15 mm;
 - broken twill 2/2 V4: warp thread system – measurement point (10 and 15 mm).

In the second stage of modelling process of the shape of fabric tearing zone, speaking more precisely the shape of zone “arms” there was assumed the following procedure:

1. In the theoretical considerations carried out (Witkowska, 2008) it was shown that the shape of tearing zone, which was formed in the both system threads the jamming point can be described by an exponential function. Therefore, the shape of “arms” of tearing zone observed on the static images presenting the tearing zones in three measurements points were also described by the exponential function:

$$y = A \exp(-Bx) + C \quad (6)$$

where: A , B and C are the constant of exponential function;

y is a value of half length of fabric tearing zone;

x is a value of depth of fabric tearing zone.

2. Modelling the shape of tearing zone „arms” was carried out for the described weaves for zones registered in the measurement point 15 mm and for the given thread system (warp/weft) for specimen No. 3. On the basis of analysis of static images of tearing zones it was assumed that the constant $C=0$.

3. In each weave variant and torn thread system (warp/weft) for calculating the constant values A and B two pairs of points (x, y) were used, i.e.:

$$(x_1, y_1) = G(0, 0, l_{\Delta\uparrow}) \quad (7)$$

$$(x_2, y_2) = E(\frac{1}{2}d_{\Delta}, l_{\Delta\uparrow e}) \quad (8)$$

where:

$l_{\Delta\uparrow}$, d_{Δ} , $l_{\Delta\uparrow e}$, are the values of tearing zone parameters read out from the static images shown in the Fig. 16.

4. The appropriate modelled curves describing the tearing zone „arms” should go through the point:

$$(x_3, y_3) = D(d_{\Delta}, 0, 0) \quad (9)$$

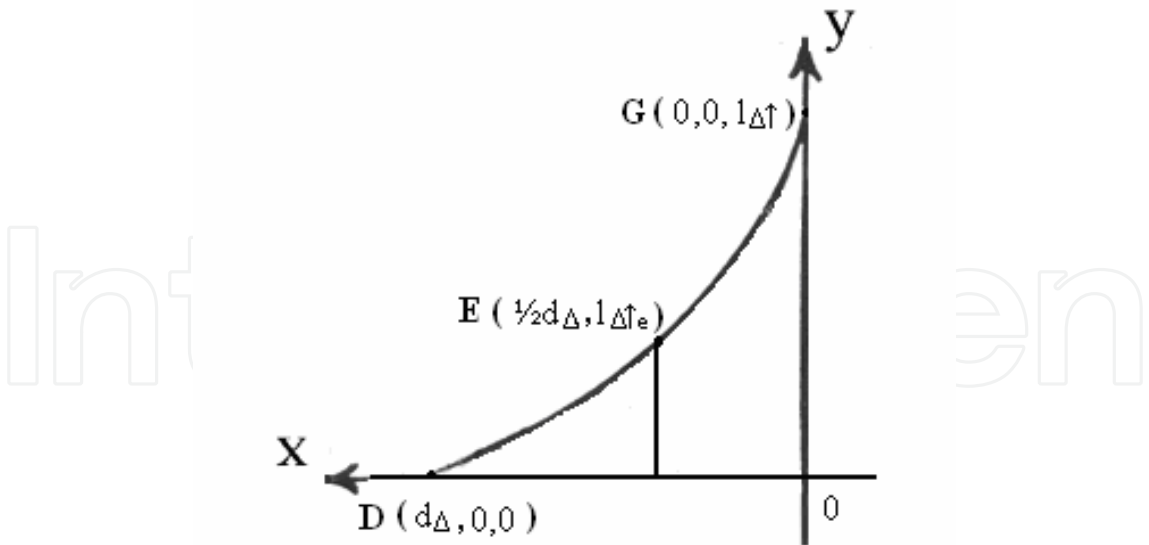


Fig. 16. The way of reading out the measurement points for modelling the fabric tearing zone „arms”
Source: own

Example:
The tearing zone “arm” shape was described for sample No. 3 made of twill 3/1Z for the warp thread system (the measurement point 15 mm).
Data: $l_{\Delta} = 6.5 \text{ mm}$, $l_{\Delta \uparrow} = 3.3 \text{ mm}$, $d_{\Delta} = 1.0 \text{ mm}$.
 $(x_1, y_1) = G(0.0, 3.3)$; $(x_2, y_2) = E(0.5, 0.2)$
Introducing the values x_1, y_1 into the equation 6 the value of constant A was calculated:

$$3.3 = A \exp(-B \cdot 0) \rightarrow A = 3.3 \tag{10}$$

Introducing the values x_2, y_2 and the value of constant A into the equation 6 the value of constant B was calculated:

$$0.5 = 3.3 \exp(-B \cdot 0.2) \rightarrow B = -5.61 \tag{11}$$

Introducing the values of constant A and B into the equation 6 the exponential equation for the following form was obtained:

$$y = 3.3 \exp(-5.61x) \tag{12}$$

Equation 12 describes the shape of tearing zone “arms” (in the first quarter of coordinate system x-y) for plain fabric in the case, when the warp was the torn thread system, and the observation point was on 15-th mm of tearing distance. The curve described by the equation 12 goes through the point $(x_3, y_3) = D(1, 0, 0)$ determining the depth of tearing zone (Fig. 17). Applying such a procedure the A and B constants of exponential functions describing the tearing zone „arm” shape for the rest fabric weaves were determined. In Table 8, there are set the values of point coordinates (x_1, y_1) , and (x_2, y_2) , necessary for determination A and B constants of exponential functions and coordinate values (x_3, y_3) determining the depth of tearing zone. In Fig. 17, there are set the chosen curves describing the “arm” shape of tearing zone of examined fabrics and presented equations of the exponential functions describing these curves.

Weave / torn system / measurement point 15 mm, specimen No. 3								
Coordinates	plain		twill 3/1 Z		satin 7/1 (5)		broken twill 2/2 V4	
	warp	weft	warp	weft	warp	weft	warp	weft
(x ₁ , y ₁)	(0.0, 3.3)	(0.0, 2.6)	(0.0, 16.5)	(0.0, 16.4)	(0.0, 21.2)	(0.0, 17.2)	(0.0, 18.5)	(0.0, 16.7)
(x ₂ , y ₂)	(0.5, 0.2)	(0.5, 0.2)	(2.5, 1.4)	(2.6, 1.2)	(2.8, 1.8)	(2.4, 1.6)	(2.8, 1.6)	(2.5, 1.5)
(x ₃ , y ₃)	(1.0, 0.0)	(0.9, 0.0)	(5.0, 0.0)	(5.2, 0.0)	(5.5, 0.0)	(4.7, 0.0)	(5.6, 0.0)	(4.9, 0.0)

Table 8. The set of values of coordinates points necessary for calculation of A and B constants of exponential functions describing the shape of „arms” of fabric tearing zone

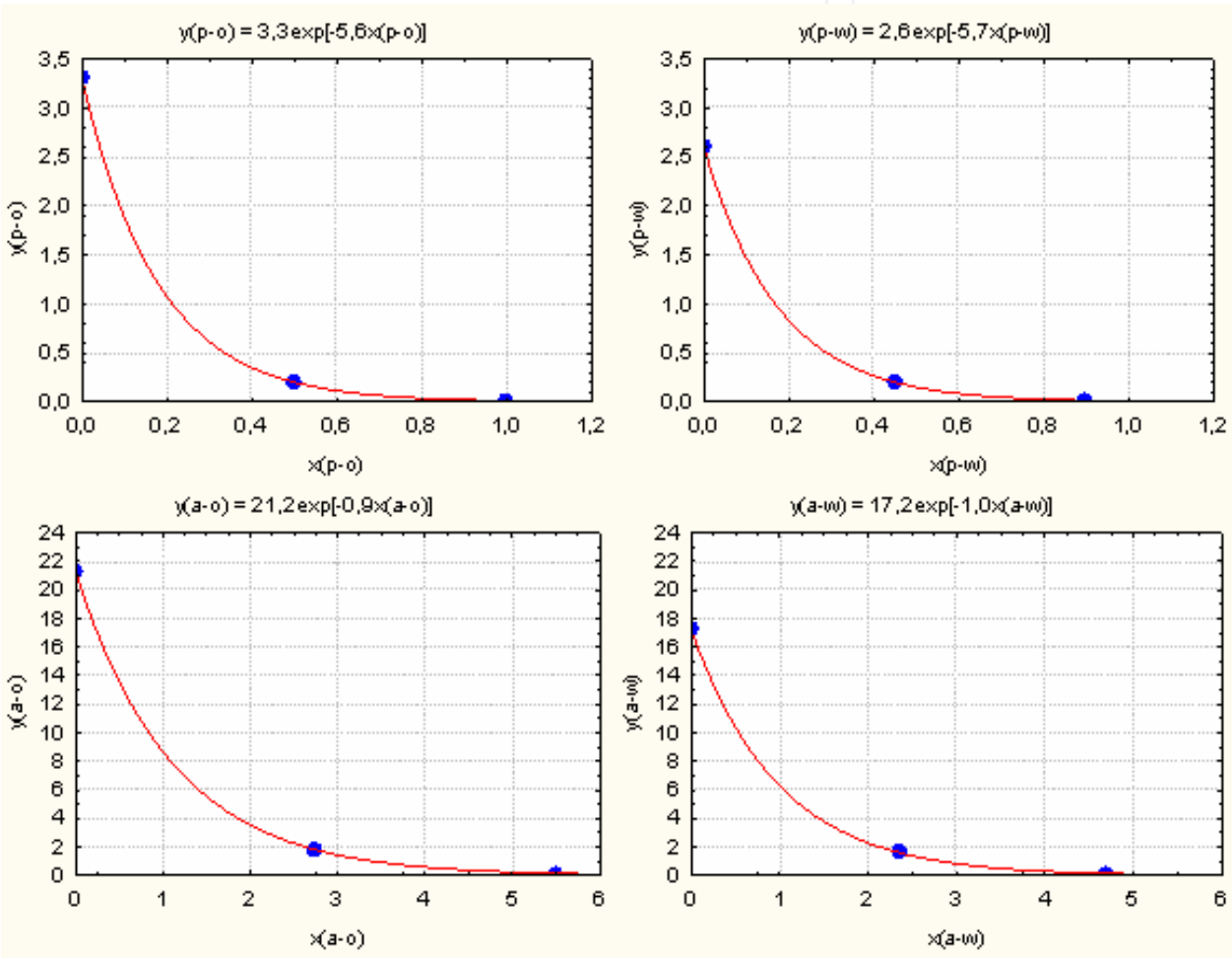


Fig. 17. Set of „arms” of fabric tearing zones of plain and satin 7/1 (5) weaves dependably on the torn thread system (warp/weft) for the measurement point 15 mm (specimen No. 3)

where: $p-o$ - warp system of plain fabric,
 $p-w$ - weft system of plain fabric,
 $a-o$ - warp system of satin 7/1(5) fabric,
 $a-w$ - weft system of satin 7/1(5) fabric,
 y - 1/2 of length of tearing zone (symbol l_{Δ} Fig. 5),
 x - depth of tearing zone (symbol d_{Δ} Fig. 5),
 exp i.e., an exponential function of basis e , of natural logarithm.

5. Summing up

5.1 The theoretical considerations on the static tearing process stages were confirmed by an experiment. It was enabled by the digital analysis of video images of fabric sample tearing. The image analysis was a very powerful measurement tool used for an identification purpose as well as for measurement of changes in the fabric structure in time due to the force acting.

5.2 The designed stand of computer image analysis, with the use of which the cotton fabric tearing was registered, aided the process of fabric phenomenon identification. The elaborated methodology enables the measurement of changes in the fabric structure in time. The additional advantage is its universality, i.e., the possibility of adapting its elements (video camera and *MicroStudio Video* software) for registration and analysis of the other phenomena. Additionally, *MicroStudio Video* software is a good tool for the result presentation. Moreover, the advantage of presented system for the computer image analysis is its multi-functionality. It can be also used for the reconstruction and measurements of changes during the other tensile destructive measurements like strength measurements and for the observation, for example, the flammability or wetting processes.

5.3 The registration of fabric tearing process and analysis of obtained static images helped to describe the parameters of fabric tearing zone such as: the length and depth of tearing zone and the number of threads in this zone.

5.4 The significant influence of fabric weave on the size of fabric tearing zone is observed. With the drop of interlacement number in the fabric, the increase of cotton fabric tear strength is observed. The lower number of interlacements causes the lower number of so called “pseudo-jammings” between the threads and in the same way, it enables the thread displacement and deformation. Simultaneously, the deformation of torn fabric specimens of weaves with the small number of interlacements is observed. Modelling the shape of “arms” of cotton fabric tearing zones showed that the “arm” shape can be described by an exponential function.

6. Acknowledgements

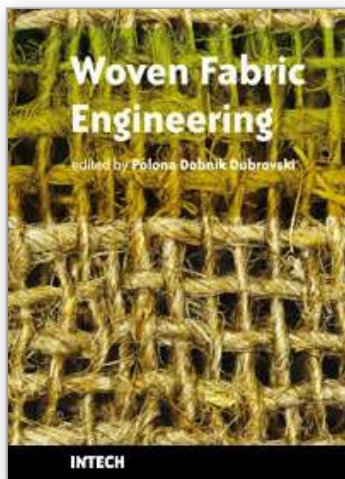
This work has been supported by: European Social Fund and Polish State in the frame of “Mechanism WIDDOK” programme (contract number Z/2.10/II/2.6/04/05/U/2/06); and the Polish Committee for Scientific Research, project no 3T08A 056 29.

7. References

- Harrison, P. (1960). The tearing strength of fabrics. Part I: A review of the literature, *Journal of Textile Institute* 51, T91-T131.
- Hamkins, Ch. P. & Backer, S. (1980). On the Mechanisms of Tearing in Woven Fabrics, *Textile Research Institute*, May, 323-327.
- Hager, O. B.; Galiardi, D. D. & Walker, H. B. (1947). Analysis of Tear Strength; *Textile Research Journal*; July, 376-381.
- Krook, C. M. & Fox, K. R. (1945). Study of the tongue tear test, *Textile Research Journal*, No. 11, 389-396.

- Scelzo, W. A.; Backer, S. & Boyce, C. (1994a). Mechanistic role of yarn and fabric structure in determining tear resistance of woven cloth - Part I: Understanding tongue tear, *Textile Research Journal*, Vol. 64, No. 5, 291-304.
- Scelzo, W. A.; Backer, S. & Boyce, C. (1994b). Mechanistic role of yarn and fabric structure in determining tear resistance of woven cloth. Part II: Modelling tongue tear, *Textile Research Journal*, Vol. 64, No. 6, 321-329.
- Teixeira, N. A.; Platt, M. M. & Hamburger, W. J. (1955). Mechanics of elastic performance of textile materials: Part XII: Relation of certain geometric factors to the tear strength of woven fabrics, *Textile Research Journal*, No. 10, 838-861.
- Taylor, H. M. (1959). Tensile and tearing strength of cotton cloths, *Journal Textile Research*, Vol. 50, T151-T181.
- Letters to the Editor (1974). Modified Tearing Model, *Journal of the Textile Institute* 65, No 10, 559-561.
- Witkowska, B. & Frydrych, I. (2004). A Comparative analysis of tear strength methods, *Fibres & Textiles in Eastern Europe*, Vol. 12, No 2(46), 42-47.
- Witkowska, B. & Frydrych, I. (2005). Protective clothing - test methods and criteria of tear resistance assessment, *International Journal of Clothing Science and Technology (IJCST)*, Vol. 17, No 3/4, 242-252.
- Witkowska, B. & Frydrych, I. (2008). Static tearing. Part II: Analysis of stages of static tearing in cotton fabrics for wing - shaped test specimens, *Textile Research Journal*, 78, 977 - 987.
- Witkowska, B. (2008). Modelling of the cotton fabric static tearing, Doctoral dissertation Technical University of Lodz, Poland.

IntechOpen



Woven Fabric Engineering

Edited by Polona Dobnik Dubrovski

ISBN 978-953-307-194-7

Hard cover, 414 pages

Publisher Sciyo

Published online 18, August, 2010

Published in print edition August, 2010

The main goal in preparing this book was to publish contemporary concepts, new discoveries and innovative ideas in the field of woven fabric engineering, predominantly for the technical applications, as well as in the field of production engineering and to stress some problems connected with the use of woven fabrics in composites. The advantage of the book Woven Fabric Engineering is its open access fully searchable by anyone anywhere, and in this way it provides the forum for dissemination and exchange of the latest scientific information on theoretical as well as applied areas of knowledge in the field of woven fabric engineering. It is strongly recommended for all those who are connected with woven fabrics, for industrial engineers, researchers and graduate students.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Beata Witkowska and Iwona Frydrych (2010). Wing Tear: Identificationn of Stages of Static Process, Woven Fabric Engineering, Polona Dobnik Dubrovski (Ed.), ISBN: 978-953-307-194-7, InTech, Available from: <http://www.intechopen.com/books/woven-fabric-engineering/wing-tear-identificationn-of-stages-of-static-process>

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2010 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](https://creativecommons.org/licenses/by-nc-sa/3.0/), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.

IntechOpen

IntechOpen