Katarzyna Kobiela-Mendrek

Programming Periodic Fatigue Research of Composites Utilised for Ski Jumping Suits by Means of Merlin Test Profiler Software

DOI: 10.5604/01.3001.0013.0749

University of Bielsko-Biała,
Institute of Textile Engineering
and Polymer Materials,
ul. Willowa 2, 43-309 Bielsko-Biała
e-mail: kmendrek@ath.bielsko.pl

Abstract
In the thesis, an example of using an Instron 5544 – a tensile testing machine for programmable fatigue research of composite material designed for ski jumping suits is described. A few basic parameters were considered in the research, such as the duty cycle of the composite under exploitation conditions, the duration of individual stages of loads, and mechanical properties of the material obtained as a result of static testing. These parameters were used to program the cycle of research on the Instron 5544 model, a tensile testing machine controlled with a computer and equipped with Merlin Test Profiler software.

Key words: *composites, fatigue strength, cycle of loads, programmable research.*

Introduction

There are many factors causing the gradual destruction of objects, namely, water in a liquid and gaseous form, UV radiation, different types of microorganisms, oxygen, and temperature changes. One of them are also repetitive, relatively small mechanical loads, causing destruction called the fatigue of material. Due to the fatigue of the material, unexpected, sudden destruction of the entire structure sometimes occurs, which generates huge costs and sometimes causes human casualties. The indications of fatigue are small, almost invisible phenomena related to gradual changes in product geometry and deterioration of its essential properties [1, 2]. The problem of the strength and fatigue life of structures and their elements was first reflected in August Wöhler's research about 160 years ago, although the first work on this subject appeared in the late 30s of the 19th century [1, 3, 4]. Depending on the way in which the elements tested are used, strength and fatigue durability are considered for specific types of loads. Such loads can be classified in terms of a number of parameters, the most common of which are the type of loads (compressive, tensile, bending and torsional), the magnitude of changes in stresses, the frequency of changes, and others. Usually the effect of sinusoidal loads described with the help of characteristic parameters is considered [5-8]. For this type of research, devices called pulsators are used, in which changes in loads result from the use of appropriate mechanical, electromagnetic or other systems [9-13], as well as tensile testing machines with a special structure [9]. The fatigue research of textile fibres has been carried out since the 1960s [13, 14] due to the emergence of new types of fibres and their utilisation for technical purposes, including the case of composites. Nowadays, when the use of textile composites is widening, it seems that fatigue research should gain in importance. As shown in the example of yarns and knitted fabrics [6, 15, 16], fatigue research of the tensile strength of textiles is possible to be carried out on an Instron 5544 – a universal testing machine equipped with appropriate software. The sinusoidal or triangular signal used in fatigue research rarely reflects the load conditions of the actual product. Therefore fatigue research under the influence of polyharmonic and even more complicated loads or elongations seems to be more useful and suitable to predict the behaviour of a particular material during its use. Typically, as an introduction to this type of research, an analysis of the actual loading course is carried out, using appropriate methods [7, 17]. The result of such analysis is the spectrum of the signal. On its basis, according to the assumed criteria, a programme of loads is created, which is then implemented and realised using a programmable machine. However, as research has shown, mainly for steel [18-20], calculations and research on fatigue life depend on the method of analysis of actual courses of the load previously used as well as on the type of programme of test loads generated on this basis. In the case of not very complicated courses of periodic loads of textiles and some laminates, it is possible to carry out simulation tests using an Instron 5544 model – a tensile testing machine, operating with a computer equipped with the Merlin Test Profiler environment [21].

The aim of the research was the preparation of a fatigue test for a specific composite, its implementation into Merlin Test Profiler software and then realisation with an Instron tensile testing machine to verify the method's usefulness for programmable fatigue research.

Research material and preliminary research

A programme of loads was developed for a special composite material intended for ski jumping suits. This material complies with the requirements of the International Ski Federation (FIS – Fédération Internationale de Ski) [22]. It is a five-layer laminate with a total thickness of 5 mm, consisting of two knitted fabrics and two layers of flexible foam with a thin flexible membrane between them. The external textile layers are bi-elastic warp-knit fabrics of locknit (charmeuse) weave, each of a mass per unit area of 180-190 g/m^2. They are situated in parallel i.e. the right side of the external fabric to the environment and the left side of the internal fabric to the human skin. The composition of the knit fabrics is 81% Polyamide gloss 44 dtex f12 and 19% Lycra monofilament 44 dtex. The volumetric weight of the open structure foam is about 55 g/dm^3 and thickness of one layer is 2 mm. The membrane mass per metre and its thickness are negligible. The layers between textiles, which were primarily air non-permeable, are perforated to obtain the required air permeability of 40 dm^3/m^{2}s [22, 23]. Composite layers are joined by flame lamination. The cross-section of the laminate with the marking of individual layers and perforations of the foam, together with the membrane, are shown in ***Figure 1***.

The aim of the preliminary research was to determine the range of loads and their duration. The research covered measuring the static strength of the composite and estimating the duration of individual phases of loads for simulation tests. The value of the breaking force and elongation at break of the laminate separately in the direction of the wales F_R and towards the courses F_K of the knitted fabrics was also established. Due to the height of the column of the machine and considerable extent of the elongation of the laminate under tension, measurements were made at a gauge length of 50 mm and tensile speed of 100 mm/min. The remaining conditions were completely in line with the standard procedure [24]. The results of measurements are presented in ***Table 1***.

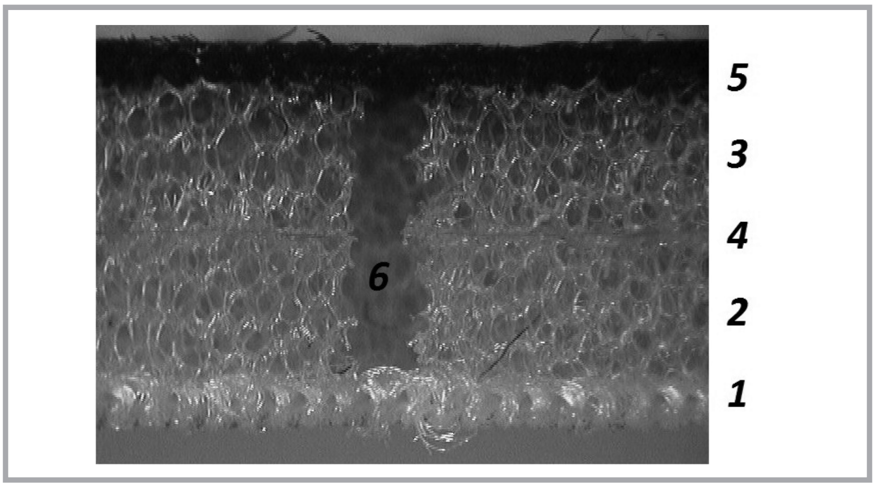


Figure 1. *Cross-section of the composite used in the ski jumping suit: 1 – "lining" inner fabric, 2, 3 – foam, 4 – membrane, 5 – outer colour fabric, 6 – perforation, (own work).*

Table 1. *Results of research on the composite's static strength, (own work).*

Load direction	Breaking force F, N	Strain at break E, %	Breaking stress σ_R, kPa
Course direction	500	600	2000
Wale direction	560	420	2240

In order to investigate the cycle of loads, an interview was conducted with athletes, who described their feelings about the degree of elongation of the material and its stresses during jumping. They assessed the strain in the material as the levels of stress. Based on the interview, as well as observation, it appears that the material of the suit undergoes the greatest tensile stresses around the knees and buttocks. These points were considered representative for the fatigue destruction of the material. The fact of compression and bending of the suit material was not taken into account, e.g. under the knees and at the flexion of the elbows.

Each ski jump consists of specific phases. It is also accompanied by typical activities preceding and following the jump. Based on source data [25] and film material, the duration of subsequent ski jumping phases was estimated. The total duration of a ski jump depends on the size of the ski jumping hill, the skills of a ski jumper, as well as on the length of the waiting time for the jump. As a basis for designing a cycle of loads of the suit, the ski jumping phase was adopted, starting with the waiting position on the start bar until the skis are unfastened. Therefore the cycle of loads consists of the following, in the order given:

- Waiting for the start signal,
- Rebounding from the start bar,
- Approach (in-run),
- Take-off,
- Flight,
- Telemark landing,
- Out-run,
- Unfastening the skis.

According to the rules of ski jumping, the waiting phase cannot be longer than 10 seconds. A value of 6 seconds was obligatorily set as a research assumption. Based on the measurements, it was established that the approach takes approx. 4-5 seconds on medium and large ski jumping hills and about 6 seconds on ski flying hills. The flight phase lasts up to 5 seconds on normal ski jumping hills and up to 8 seconds on ski flying hills. The duration of the phases, which can be considered typical for normal ski jumping hills, was adopted for the research.

At each stage of a jump, the competitors take up a certain position of the body, which results in stresses in the suit material. Based on the description of the jumpers' feelings, it was determined that the greatest temporary stresses of the suit occur at the time of accepting the approach position, with comparatively lower stress levels occurring in the set approach position and temporarily during the telemark. Even lower stresses affect the material of the suit while waiting for the start signal when the competitor is sitting on the start bar and subsequently while unfastening the skis. For the flight phase a zero stress level is assumed because the competitor is maximally straight and only their feet are bent forward. The individual levels of loads were determined as relative values of the breaking force, assuming that the highest load cannot exceed 50% of the breaking force, and the remaining grades were levelled at 25%, 15% and 10% of the breaking force. For example, the level of the load during "waiting" was set as 10% of the breaking force (***Table 1***), which means that for the course direction it is 50 N.

Data of the course of the loads of the suit determined on the basis of the interview and measurements are given in the graph (***Figure 2***), which was the basis for designing a cycle of loads for programmable research.

Designing a research procedure using the Merlin Test Profiler environment

To design the procedure of periodic programmable research, the Tensile Test Profiler module available in Merlin software was used. The Test Profiler is an option of Merlin software that enables to customise cyclic testing using the Compression Profile and Tension Profile test types. It also allows to design periodic research, control work, collect data from an Instron tensile testing machine, and visualise the course of loads, stresses and elongations.

The Test Profiler allows to create cyclic tests by choosing an appropriate shape from a series of blocks. The cyclic test may consist of triangles, ramps and holds (horizontal line that symbolises a constant level). Then the customer should specify the control mode and parameters

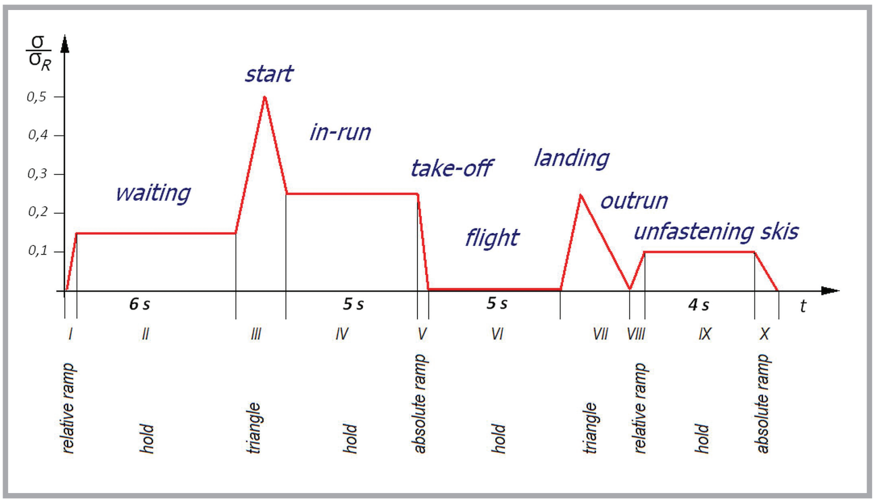
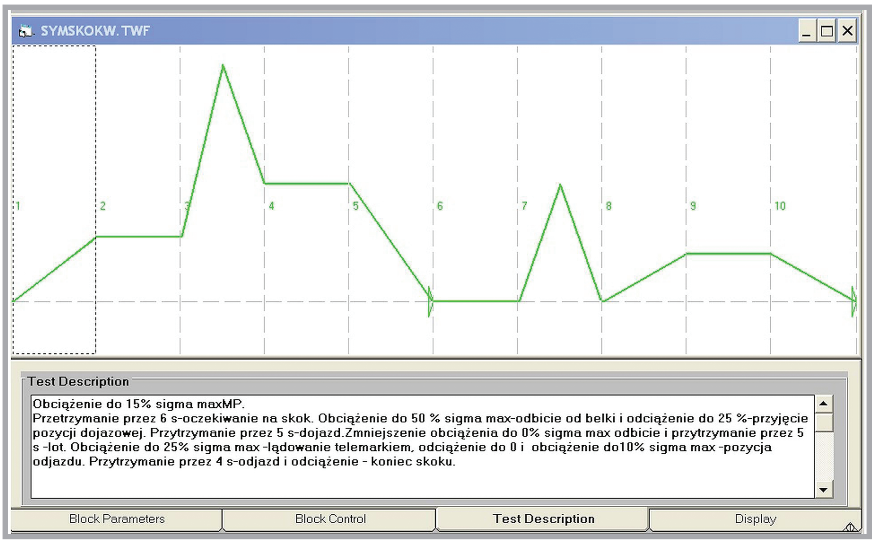


Figure 2. *Chart of composite loads during a ski jump divided into elementary courses, (own work).*



Test Description

Obciążenie do 15% sigma maxMP.
Przetrzymanie przez 6 s-oczekiwanie na skok. Obciążenie do 50 % sigma max-odbicie od belki i odciążenie do 25 %-przyjęcie pozycji dojazowej. Przytrzymanie przez 5 s-dojazd.Zmniejszenie obciążenia do 0% sigma max odbicie i przytrzymanie przez 5 s -lot. Obciążenie do 25% sigma max -lądowanie telemarkiem, odciążenie do 0 i obciążenie do10% sigma max -pozycja odjazdu. Przytrzymanie przez 4 s-odjazd i odciążenie - koniec skoku.

Figure 3. *Fragment of the Merlin Test Profiler environment window with a simulation programme of the composite loads and its description, (own work).*

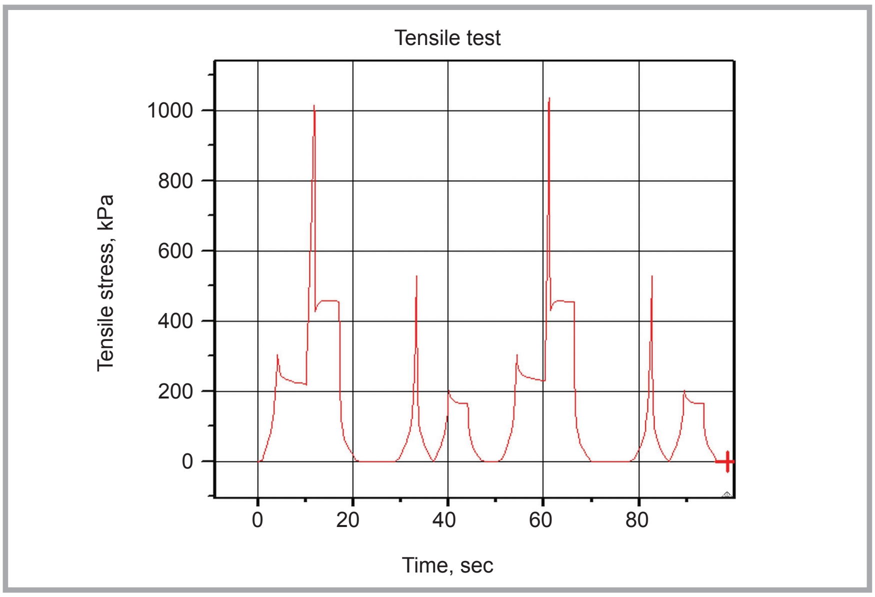


Figure 4. *Chart presenting changes in stresses during programmable fatigue research, (own work).*

for each shape. The outcome is visible in the program window as a broken line [21, 26].

The chart of loads prepared (***Figure 2***) was divided into simple courses-segments that are analogous to the types of block shapes implemented in the Merlin Test Profiler [21]. Each elementary course was described by its characteristic values. Detailed characteristics of the segments of loads representative for subsequent types of block shapes are presented in ***Table 2***. The load values were recorded as fractions of the breaking force F from ***Table 1***. Since the flat laminate samples are characterised by a fairly high bending stiffness, they were not subjected to a pre-load during clamping. Due to the necessity of carrying out research separately for the longitudinal and transverse directions of the composite, two cycle variants were finally programmed, differing in values for particular load levels, as shown in ***Table 1***. Within the entire load cycle, each type of triangular signal with specified parameters (phase III and phase VII) occurs once, therefore the number of repeats (cycles) was 1 each time. However, it is possible to create identical triangular signals as part of the sequence test by programming an appropriate number of cycles for this block signal.

All available types of block shapes were used to design the procedure. Separate attention was paid to the line speed of the clamps. For the most faithful mirroring of the dynamics of the competitors' movements, the highest possible speed was assumed. As a result of the tests, a speed of 30 mm/s was assumed to be optimal, which was the maximum value at which it was possible to perform all test sequences without an emergency shutdown of the machine.

The programme of the course of periodic loads of the composite designed in the Merlin Test Profiler environment, along with a description, are shown in ***Figure 3***. As is apparent in comparison with ***Figure 2***, the course of loads obtained in the Merlin Test Profiler on the basis of the data entered differs slightly from the original chart of loads. This is due to the constant, independent of the time parameter, width of the load blocks in the Test Profiler window.

In order for the entire test sequence to be performed repeatedly, it should be marked in the Block Control tab. Since the test should end with breaking of the sample, a sufficiently large number of repetitions had to be introduced. In the case of the procedure presented and the material tested, a number of 10.000 was found to be sufficient. With a fixed number of repetitions after which there is no destruction of the sample, when the last cycle is completed, it is possible to program a specific method of ending the test. It may be stopping the machine in the final position, stopping and returning to the initial state (initial length) or a direct return to the initial state.

Table 2. *Parameters of the programme of composite loads on ski jumping suits (loads expressed in fractions of the breaking force), (own work).*

Phase no.	Type of block shape	Parameter of block shape	Selected parameter or parameter value	Unit
I	Relative ramp	Delta	0,15*F	N
		Rate	30	mm/s
II	Hold	Criteria	Rate of change	–
		Channel	Tensile stress	–
		Rate	0	mm/s
		Duration	6	s
III	Triangle	Maximum	0,5*F	N
		Minimum	0,25*F	N
		Rate	30	mm/s
		Cycles	1	–
		Initial waveform direction	Maximum limit	–
IV	Hold	Criteria	Rate of change	–
		Channel	Tensile stress	–
		Rate	0	mm/s
		Duration	5	s
V	Absolute ramp	End point	0	N
		Rate	30	mm/s
		Ramp set-up	Rate	–
VI	Hold	Criteria	Rate of change	–
		Channel	Tensile stress	–
		Rate	0	mm/s
		Duration	5	s
VII	Triangle	Maximum	0,25*F	N
		Minimum	0	N
		Rate	30	mm/s
		Cycles	1	–
		Initial waveform direction	Maximum limit	–
VIII	Relative ramp	Delta	0,10*F	N
		Rate	30	mm/s
IX	Hold	Criteria	Rate of changes	–
		Channel	Tensile stress	–
		Rate	0	mm/s
		Duration	4	s
X	Absolute ramp	End point	0	N
		Rate	30	mm/s

The Block Control tab was also used to select the starting block for repetition. For the procedure designed it was block I, but in justified cases one can choose any kind of block, from I to IX, as the starting block for the repetition. For instance, if the stress of a composite is not very important for its fatigue wear to be considered during the period of waiting for a jump, one can use the waiting phase only once, and then repeat the whole cycle from the moment of rebounding from the start bar to the end, that is from block 3 until block 10 is completed.

In line with the programme prepared, fatigue research of the composite was carried out. The samples and spacing of the clamps of the machine were the same as in the case of static tests. A fragment of the chart of changes recorded by the system as a function of time is shown in ***Figure 4***.

The chart of stresses only covers about two and a half cycles of loads of the composite. There is no full chart covering the several hundred cycles to break the sample due to its illegibility resulting from the density of the graph lines. They are visible as a compact block with a rectangular shape.

Unfortunately the system does not count the completed cycles. Therefore to obtain a numerical result, an additional analysis of the chart was necessary. It was carried out by counting the cycles, or actually the maxims, from fragments of the chart covering successive sections of the study. At the same time, it was found that the frequency of machine operation changes only slightly during the whole test, despite the fact that at a constant speed of movement of the clamp its length increases along with an increase in sample elongation. As results from the analysis of the chart shown in ***Figure 5***, one cycle of machine operation takes about 42 seconds, and after omitting the phase of unfastening the skis – about 33 seconds, which corresponds to a frequency from 0.024 to 0.03 Hz. In the actual conditions, assuming that the waiting phase for the start signal is 6 seconds, this time is about 16-17 seconds or around 0.06 Hz. The reason for the differences is probably the significantly lower dynamics of the operation of the machine compared to the competitor, or perhaps a mistake made when estimating the functional stresses.

Summary and conclusions

An Instron 5544 tensile testing machine controlled with a computer with Merlin Test Profiler software installed is useful for carrying out fatigue tests on textiles and laminates related to their tensile strength in the low frequency range. The software also enables the creation and implementation of procedures for programmable fatigue research including the phases of growth, depression and maintenance of a given load, force or elongation. Programmed courses are obviously extremely simplified in comparison to the real courses of loads. The usefulness of the method was proven by preparing and implementing a programme of loads of the laminate for ski jumping suits. The Merlin Test Profiler offers a number of useful tools, however the implementation encounters constraints resulting from the design and principle of operation of the driving element. In particular, a barrier is the maximum possible travelling speed of the clamps, which should not exceed 30 mm/s.

Determination of the fatigue life of the material, expressed in the number of cycles to the moment of break, requires additional analysis of the charts.

The method may be useful for textiles, especially those that work under changeable loads, to determine their fatigue life; however, it demands input data.

Monitoring of changes in materials' structure under different levels of loads in a cyclic test may also be a very interesting issue.

Acknowledgements

The issues raised in the article were in part the subject of speeches given at the 15th World Textile Conference Autex 2015 and the 18th Scientific and Technical Conference – Construction – Geosyththetics-Logistics, Ustroń 2015.

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Received 08.11.2018 **Reviewed 04.03.2019**