INVESTIGATIONS ON THE POSSIBILITY OF OBJECTIVE CHARACTERISATION OF SAILCLOTH

E. Vujasinovic[1], R. Cunko[2], Z. Bezic[3]

[1]University of Zagreb, Faculty of Textile Technology, Prilaz baruna Filipovica 30, HR-10000 Zagreb, Croatia, edita.vujasinovic@zg.htnet.hr
[2]University of Zagreb, Faculty of Textile Technology, Savska 16, HR-10000 Zagreb, Croatia, rcunko@ttf.hr
[3]Victory sailmakers – Intervela d.o.o. Bac pri Materiji, SI-6242 Materija, Slovenia, victory@soil.net

Abstract

Although modern sailcloth materials are extremely complex, a considerable degree of disorder is still present in the evaluation of their quality, and experience is still the most important parameter in assessing a product. For those reasons, precise characterisation and evaluation of modern sailcloth is a topic that requires systematic investigation, both in view of defining relevant characteristics & parameters, and in defining and adapting adequate testing methods and procedures & evaluation of results. The paper presented here is a contribution to the scientific and professional approach to the topic.

Key words:

sailcloth, objective evaluation, quality, characterisation

Introduction

Objective measurements and evaluation are now an integral part of the preparation, marketing and processing of many textile goods [1], but for some of them, like sailcloth for example, they are still not employed on a regular basis [2]. Although modern sailcloth belongs to the group of high-performance and high-tech materials, the assessment of its fitness for use is mostly based on the sail-makers' subjective judgment and experience [3]. In order to implement the concept of objective measurements and evaluation in the sail-making processes (Figure 1), the possibilities of objectively characterising the materials intended for sail manufacture are investigated and defined, with respect to the specific principles of sailing and the requirements of the material for this purpose [4].

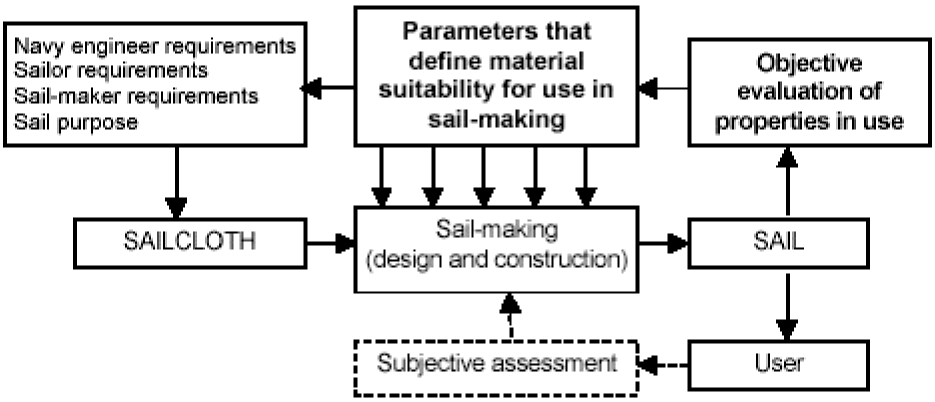


Figure 1. Schematic representation of the objective measurements implementation in the sail-making process

A material (cloth, yarn or fibre) should meet a number of requirements for use in sail manufacture. These requirements can, depending upon a particular point of view (that of the naval architecture engineer, sail-maker or sailor [5]) contradict each other to a certain degree, supplement each other, and/or even be identical (Figure 2). From the naval engineer's point of view, a material to be used in sail manufacture should, besides having a smooth surface, have zero porosity, ensuring effective air flow around the sail [2, 4, 6] and creating an aerodynamic force to push it. To reduce the proportion of the force created which cannot be used (i.e. resistance to airflow), the surface roughness of the sailcloth should be as low as possible. A further requirement, or limitation, to be met by the sailcloth is low surface mass, in order to reduce the moment of swerving, and with it, the tilting of the sailboat. The sailor, like the navy engineer, is the end user of the sail, and so he requires sails of lower mass, to facilitate handling. However, in order to sail more comfortably and safely, the yachtsman also demands strong sails, of a stable shape, which are easy to maintain. The sail strength (the cloth and joining parts and/or seams) should be such that the sails can stand strong wind or sudden squalls, and not be torn or change shape significantly, as this reduces the need to adapt the sail shape instantly to momentary conditions. In addition, the sailcloth must resist water, sunlight and microorganisms, and must also display a good ratio of price and durability. The final decision in selecting the fabric for the manufacture of sails rests on the sail designer. His task is to turn the designed shape into a sail, balancing the forces of wind and strains in the sail. As each particular sail is designed for a precisely defined range of wind strength, the resulting pushing forces of the wind on the sail will determine the limits of the necessary fabric strength. As the push is highest when sailing downwind, breaking force will be a decisive factor in manufacturing spinnakers, while in selecting the fabric for the headsail and the main sail (where stability of form is more important than maximum force), the decisive factor will be the yielding point, or fabric elasticity [2].

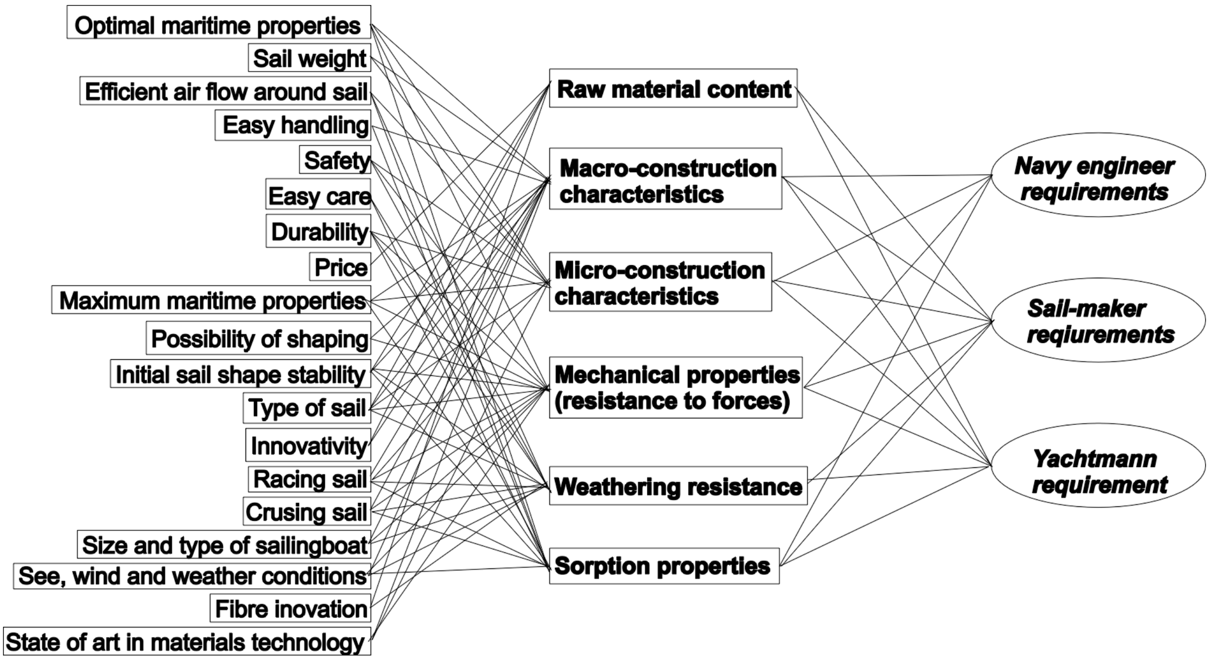


Figure 2. Design of sailcloth quality descriptors

Methodology

Bearing the above goals in mind, but also considering the possibility of establishing an expert system that would make the evaluation of material behaviour possible under real end-use conditions, 12 representative samples of modern sailcloth of various constructions were selected (Table 1).

The samples have been used to test six groups of properties (or parameter blocks), that determine in detail the suitability of a particular material for the manufacture of sails with predetermined end-use properties (Figure 2). The parameter blocks are as follows: chemical composition, macro- and micro-construction, sorption properties, resistance to wide variety and intense of forces, and resistance to ageing under natural conditions.

Appropriate standardised testing methods (Table 2) have been used to investigate the above properties, some of them for the first time in this context (KES System). A statistical evaluation of the importance of each quality factor has been implemented to assert the suitability of the parameter blocks selected.

Table 1. Description of the sailcloth samples tested

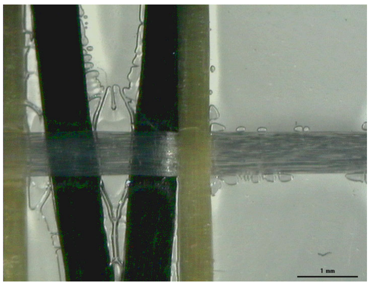
Sample	Trade mark	Producer	Description of sailcloth
1	3,4 us oz	Contender, USA	Woven cloth; mass per unit area < 150 gm^{-2}
2	3,7 us oz	Polyant, USA	Woven cloth; mass per unit area < 160 gm^{-2}
3	Cuben fiber 0,5 mil film; 1,3 us oz	Cuben, USA	Laminated cloth; mass per unit area < 60 gm^{-2}; film thickness ~12,7 μm
4	Cuben fiber 0,3 mil film; 0,9 us oz	Cuben, USA	Laminated cloth; mass per unit area < 30 gm^{-2}; film thickness ~7,6 μm
5	Spectra 1,8 us oz	Bainbridge, USA	Laminated cloth from Spectra® fibres; mass per unit area < 80 gm^{-2}
6	Polyester 1,8 us oz	Bainbridge, USA	Laminated cloth from polyester fibres; mass per unit area < 80 gm^{-2}
7	Polyester 2,3 us oz	Challenge, USA	Laminated cloth from polyester fibres; mass per unit area < 100 gm^{-2}
8	Kevlar 1mil film; 2,2 us oz	Dimension, USA	Laminated cloth from Kevlar® fibres; mass per unit area < 100 gm^{-2}; film thickness ~25,4 μm
9	Kevlar 0,75 mil film; 1,5 us oz	Dimension, USA	Laminated cloth from Kevlar® fibres; mass per unit area < 100 gm^{-2}; film thickness ~19,1 μm
10	Kevlar with X ply; 2,4 us oz	Dimension, USA	Laminated cloth from Kevlar® fibres; mass per unit area < 110 gm^{-2}, with additional X skrim
11	PBO 4,85 us oz	Dimension, USA	Laminated cloth from PBO fibres; mass per unit area < 210 gm^{-2}
12	Monofilm 3,1 us oz	Bainbridge, USA	Polymer film; mass per unit area < 140 gm^{-2}

Table 2. Proposed testing methods and procedures

Parameter	Methods and procedures	
Qualitative analysis	FT-IR spectroscopy	ASTM D 276-87^E, comparison with FT-IR spectrograms according to; Perkin-Elmer Spectrometer, Model 2000/KBr matrix; IRDM software package
Micro- and macro-construction characteristics	Fabric count	HRN F.S2.013
	Fabric thickness	ASTM D 1777-64 (respectively in DIN 53855/1,2,3; HRN F.S2.021); Kawabata Evaluation System for KES-FB-3
	Mass per unit area	HRN F.S2.016
	Microscopic appearance	Microscopy - Stereomicroscope NIKON SMZ-2T equipped with Sony CCD-IRIS CV camera linked to a computer and software package for image processing and analysis (Lucia M-Laboratory Imaging Ltd.,); Zeiss AXIOTECH Microscope with transmitted and polarized light in the connection with Sony CCD-IRIS/RGB CV camera linked to a computer using software package (KS 300-Kontrol Electronic Ltd.) for image processing and analysis.
	Surface characteristics	Kawabata Evaluation System for KES – FB-4
Mechanical properties	Tensile properties	ASTM D1682 (respectively in DIN 53837; HRN F.S2.017); dynamometer ZWICK backed by a computer (PC software Z7005); Kawabata Evaluation System for KES-FB-1
	Tear resistance	ASTM D 1424 (respectively in DIN 53862)
	Flex strength	DIN 53362
	Crease resistance	DIN 53890 & DIN 53891/1,2
Water absorption	Wetting angle	NRL.C.A. Goniometer Model No A-100, Rame-hard
Weathering resistance	Microscopic appearance, Surface characteristics, Tensile properties, Tear resistance, Flex strength and Crease resistance after exposure to the natural aging during 2; 4; 9; 30; 60; 90 days at the geographic location: Cape Seca, Portoroge Bay, Slovenia: *45⁰28,7`N13⁰28,7`E*	

Objective Measurements And Evaluation Of Sailcloth

The systematic approach to objective material characterisation (Figure 2) has resulted in a sailcloth quality card as a kind of quality assurance, and a key element for production optimisation and improvement of the end-product's quality. The quality card that includes Figures 3÷6 & Tables 3÷6 is designed in order to permit:



a)

b)

Figure 3. Microscopic appearance of sample no. 10: a) 40x magnified in reflected light; b) binary picture 3a

Table 3. Raw material content for sample no. 10

Raw material content			
Warp (0^0)	Fill (90^0)	Diagonal yarn (0^0)	Film
AR Kevlar®	PE Spectra® PEN	AR Twaron®	PES Mylar®

Table 4. Micro- and macro-construction quality descriptors for sample no. 10

Macro- & micro-construction			
Type of cloth	Laminate F/S+d/F	U_{nvl} [%]	8,32
g_0/g_{90} (g_d) [/10cm]	29,9/15,3 (10,3)	N_Z [m^{-2}]	15,1x10^5
$d_{0/45}$ [mm]	0,509/(0,712)	A_Z [mm^2]	0,0546
d_{90} [mm]	0,955 (0,758)(1,315)	MIU	0,2029
T_{100} [mm]	0,223	$SMD_{0/F}$ [μm]	1,5927
m_A [gm^{-2}]	103,53	$SMD_{0/B}$ [μm]	1,8457
ρ_{Rx} [gm^{-3}]	0,46	$SMD_{90/F}$ [μm]	6,1902
U_{pvl} [%]	50,98	$SMD_{90/B}$ [μm]	6,4013
$N_{F/F}$ [m^{-2}]	2,9X10^9	$SMD_{45/F}$ [μm]	4,5218
$A_{F/F}$ [mm^2]	1,6690	$SMD_{45/B}$ [μm]	3,2032
Uniformity	NO (construction)	YES (film)	Isotropic

- primary classification and sailcloth evaluation by end-use (manufacture of racing or cruising sails), as well as by the weather-location conditions of the intended use. Although the decision can be taken on the basis of a number of indicators, the most evident is the time of cloth destruction and the trend of the change in tensile properties, as effective aerodynamic flow and optimal maritime sail properties are higher on the scale of importance than durability, at least for racing sails.
- secondary classification and sailcloth evaluation, based on end-use and defined by naval architect requirements for the type of sails adequate for the type and size of the vessel designed. For example, establishing the required size of the sails for the purpose of sail-ship stability sets limits to the maximum sailcloth surface mass. It is also possible, on the basis of surface roughness and the adequate friction coefficient, to precisely define the effectiveness of aerodynamic airflow, which means the efficiency of the sail itself.
- tertiary classification and sailcloth evaluation based on the sail-maker's requirements for the processability of a 2D fabric into a 3D sail form. For example, quality parameters (determining resistance to tensile forces) in a particular direction of the sailcloth is a key factor in designing sails and selecting the technique of its manufacture (panel or radial cut).

- end-user sailcloth evaluation, as an ideal cloth is considered to be one with as low a ratio of price and durability as possible (raw material content; appearance; weathering resistance), which at the same time offers maximum maritime properties for the sailing ship (i.e. as low a ratio as possible between sail strength and its mass, and as smooth a surface as possible) and security (resistance to high loads and prolonged tearing; weathering resistance), as well as easy handling and maintenance (flexing ability; compressibility; volume mass; hydrophobicity).

Conclusion

The investigations described and the knowledge obtained form a basis for the construction of an expert system to be used to evaluate the behaviour of each sailcloth material in its end-use, starting from objective measurements of each new and potentially applicable sailcloth, and to assess its value, usability and effectiveness for a specific end-use.

Acknowledgement

The investigations presented here are part of a broader research project organised in the Department of Textile Chemical Technology and Material Testing, Faculty of Textile Technology, University of Zagreb, Croatia, in collaboration with a well-known sail manufacture company (Victory – Intervela d.o.o., SI). Here we also wish to express our gratitude to Prof. Ph.D. Jelka Gersak for giving us the opportunity to perform some new, non-standard tests in her laboratory at the Faculty of Mechanical Engineering, University of Maribor, Slovenia, during the CEEPUS exchange program.

References

1. *P. Sommerville, Objective Measurements – more than pretty numbers, Proceedings of Australian Wool Testing Authority Seminar – Working with Wool, Canberra, 1998*
2. *B.E. Doyle, Strong Fabrics for Fast Sails, Scientific American, 1997,* ***277,*** *7*
3. *E. Vujasinovic, R. Cunko, Spectra – one of the latest sailcloth wonder fibres, Proceedings of the 1st AUTEX Conference TechniTex 2001, Ed. Mario Araujo, Povoa de Varzim, 2001*
4. *E. Vujasinovic, Istrazivanja mogucnosti objektivne karakterizacije materijala za izradu jedara, Dissertation, University of Zagreb, Croatia, 2003*
5. *T. Whidden, M. Levitt, The Art and Science of Sails, St. Martin's Press, New York, 1990, 11-72*
6. *W. Ross, Sail Power – The Complete Guide to Sails and Sail Handling, Alfred A. Knopf Inc., New York, 1989, 375-424*

∇∆