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RAW MATERIAL BEHAVIOUR ANALYSIS OF THE PARACHUTE SYSTEM RECOVERY AT LANDING

ENE Alexandra Gabriela[1], MIHAI Carmen[1], JOMIR Mihaela[1], SCARLAT Razvan[1], GROSU Catalin[1]

[1] The National R&D Institute for Textiles and Leather, IT Research Department in Industrial Engineering, 6 L. Patrascanu Street, postal code: 030508, Bucharest, Romania, E-Mail: alexandra.ene@incdtp.ro

Corresponding author: Jomir Mihaela, E-mail: mihaela.jomir@incdtp.ro

Abstract: *For the stabilization and braking of military aircraft during operations, special parachutes are used, which the pilot decouples, thus allowing the restoration of the flight attitude. The parachutes used for landing drag of MiG 29 Sniper supersonic aircraft are made of p-aramid yarn fabrics. The paper presents the experiments performed in the accredited laboratories of INCDTP regarding the analysis of the behavior of p-aramid fibers and threads in order to obtain the fabric that is used to make the braking systems. The stretching behavior of the para-aramid filament in the conditioned and wet state showed that it has a rectilinear path of the curves, different from the curvilinear and continuous one of the usual textile fibers, and the high elastic modulus will cause small deformations under the action of a force. The decrease in the values of resistance and elongation at break and the mechanical breaking work for the para-aramid filament in the wet state is determined by the penetration and attack of water in the amorphous phase in the microcapillaries of the fiber. On the other hand, the behavior of the para-aramid thread after the winding and weaving operations highlighted the fact that very large deformations of some constituent filaments appeared, in some cases even their rupture (reaching the limit load), which determines a redistribution of tensions throughout the yarn, avoiding breakage and the yarn proves that it no longer has a brittle material behavior.*

Key words: *parachute, canopy, deceleration system, para-aramidic yarn, statistical data.*

1. INTRODUCTION

In the aeronautical field currently are used a wide range of parachutes, differentiated in terms of raw material, shape, as well as aerodynamic performance: stability, air resistance, air drag resistance, opening speed and altitude. The most important application of textile materials is the one in which they are integrated in the set of recovery systems for supersonic aircraft, bumpers and space capsules (planetary parachutes). The aerodynamic characteristics of a deceleration system refer to the value of: the ratio Dc / D_0 (Dc = diameter of the parachute, obtained from the design and D_0 = nominal diameter of the parachute); ratio Dp / D_0 (Dp = projection diameter in the opened state); air drag coefficient and oscillation angle. ∝ [1,2] Thus, for the main parachute canop y, p-aramid yarn fabrics are used if the application of the deceleration system aims at:

- break (**Fig. 1**) the shape of the main parachute is surface guidance without ribbons, with D_c/ D_0 = 0,66; D_p / D_0 = 0,62; C_{x0} = 0,30 – 0,34; $\propto = 0° \div \pm 3°$). They operate very well at speeds from 0,1 Mach (34,0 m/s) pînă la 1,4 Mach (476,53 m/s). [1,2]

- stabilization - deceleration bombers (**Fig. 2**) with a mass of 160,000 lbs (72,480 kg) at altitudes of at least 30,000 ft (9,150 m). [3] For these parachutes the shape is surface guidance with ribbons which allows to obtain the following aerodynamic characteristics: $D_c/ D_0 = 0,63$; $D_p / D_0 = 0,62$; $C_{x0} = 0,28 – 0,42$; $\propto = 0° \div \pm 2°$ [2,3].
- for the descent of space shuttles from an altitude of 18,000 ft (5490 m) and dynamic pressures of at least 90 lb/ ft^2 (4.87 kg / m2). (**Fig. 3**) [1.5]. The aerodynamic characteristics of these types of parachutes - parawing - are: $D_c/ D_0 = 1,0$; $C_{x0} = 1,1$ (MIL –C – 38351) [4,6].

Fig. 1: *Surface guidance without ribbons parachute*

Fig. 2: *Surface guidance witht ribbons parachute*

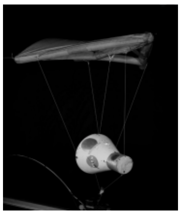

Fig. 3: *Parawing*

- stabilization - deceleration on landing supersonic aircraft, due to the excellent aerodynamic characteristics: high forward resistance coefficient and stability, which do not allow the intervention of the system in the stability of the aircraft. (**Fig.4**) The shape of these parachutes is cross and the following aerodynamic characteristics can be obtained: $D_c/ D_0 = 1,15 - 1,19$; $D_p / D_0 = 0,66 - 0,72$; $C_{x0} = 0,60 – 0,85$; $\propto = 0° \div \pm 3°$ [4]
- descents - planetary braking of capsules and space modules (**Fig. 5**), when it comes into operation from altitudes of 100,000 ft (30,500 m), at speeds higher than 3 Mach (1021.14 m / s). These parachutes are hemispherical and have the following aerodynamic characteristics: $D_c/ D_0 = 0,62$; $D_p / D_0 = 0,62$; $C_{x0} = 0,30 – 0,46$; $\propto = \pm 2°$ [4.7]. Space shuttles are also used for deceleration on landing, with a maximum landing mass of 240,000 pounds (108720 kg), a maximum opening speed of 230 kts (118.4 m / s) (Img. 5). [1,4,7] and supersonic aircraft to a maximum landing mass of 45,000 pounds (20,385 kg), at a maximum opening speed of 173 kts (89.02 m / s). [1].

Fig. 4: *Cross parachutes for deceleration and stabilization*

Fig. 5: *Hemisflo parachute for space probe, capsule or module and shuttle deceleration*

- lowering the space shuttle modules (**Fig. 6**) because the following performances are required: gliding ratio: 0.85; turn: 180 ° in 3 seconds, plus landing requirements in a preset area at a wind speed of min. 30 kts (15.44 m / s), the opening forces should be from 3 to 4 g, the landing impact forces should allow 4 g to be reached and obstacles from the ground could be avoided. These parachutes are known as Le Moigne (Paracommander) and have the following aerodynamic characteristics: $D_c/ D_0 = 1,0$; $C_{x0} = 0,9 – 1,0$. [6,7,8]
- deceleration on landing of supersonic bombers (**Fig. 7**) [6,7] Parachutes for supersonic aircraft have diameters of 14.5 - 16 ft (4.42 - 4.88 m), for landing speeds of 180 - 200 kts (333.5 - 370.6 km / h). [6,8,9] Canopies must meet MIL-C-8021 requirements. The parachute used in bombers is 15.6 ft (4.76 m) in diameter to decelerate 128,000lb (57,984 kg) at 30,000 ft (9,150 m) and must meet the

requirements of MIL 3835. The design for these types of applications is annular [9, 10] and must develop the following aerodynamic characteristics: $D_c / D_0 = 1,10$; $D_p / D_0 = 0,67 - 0,69$; $C_{x0} = 0,45 – 0,50$; $\propto = 0° \div \pm 3°$ [10]

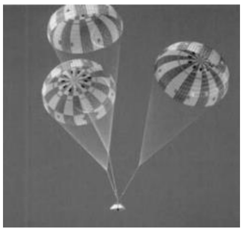

Fig. 6*: Le Moigne (Paracommander)*

Fig. 7*: Annular parachute*

2. MATERIAL AND METHOD

2.1. Analysis of the behavior of para-aramid fiber

The design criteria for the parachute recovery system of MiG 29 Sniper supersonic aircraft were based - by INCDTP specialists - on the physical phenomena underlying the deceleration on landing, namely turbulent motion and air velocity in front of the canopy tending to zero at a point of stagnation in front of the leading edge of the wings of the main parachute. The structural analysis of the canopy was performed using a specialized software The structural analysis of the deceleration parachute canopy was performed through a specialized program that allowed the identification of the values of the main parameters for the woven structure and the raw material from which it is made. In this respect, the fabric must meets the following requirements: - temperature resistance developed behind the aircraft engines: min. 300 ° C; - resistance to difficult weather conditions; - small mass and volume, determined by the aircraft configuration. These extremely restrictive requirements for a textile material can be met by using a raw material with special characteristics, represented by para-aramid yarns. In order to establish the main directions regarding the behavior on the technological flow from the weaving preparation, the behavior of a yarn with a density density of 220 dtex/f 134 was analyzed, as well as of the constituent filaments. Additionally, in order to highlight the changes in the characteristics of the yarn on the technological flow of processing, physical-mechanical analyzes were performed after dyeing and warping operations. The determinations were performed in INCDTP accredited laboratories according to SR EN ISO / CEI 17025: 2001. Para-aramid filaments with a fineness of 1.64dtex (average diameter of 12.79µm) were tested to the tensile stress in a wet and conditioned state. The stress / strain diagrams were drawn (**Fig. 8** and **Fig. 9**).

To verify the behavior in the technological processes, as well as the fragility of this type of filament, the breaking strength, the elongation at break and the mechanical work of breaking in the form of a loop were determined. The stress/strain diagrams resulting from the determinations are shown in **Fig. 10.**

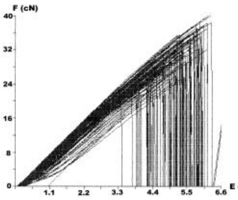

Fig. 8*: Stress-strain diagram – conditioned state testing*

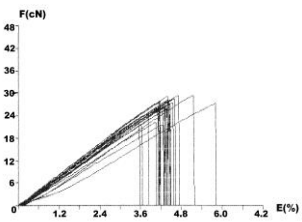

Fig. 9*: Stress-strain diagram – wet state testing*

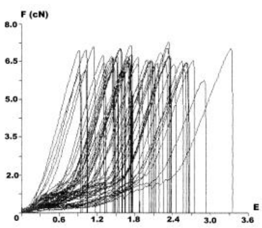

Fig. 10*: Stress-strain diagram – loop testing*

2.2. Para-aramid yarn behavior analysis

To demonstrate the tensile behavior of p-aramid yarn, the para-aramid yarn 220dtex / f134 was tested, in a conditioned, wet state and after heat treatment at 250°C. The obtained stress / strain diagrams are illustrated in **Fig. 11, Fig. 12** and **Fig. 13.**

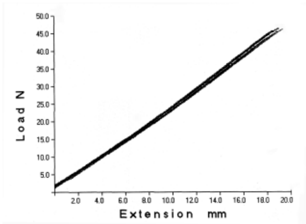

Fig. 11*: S*tress-strain diagram – conditioned state testing

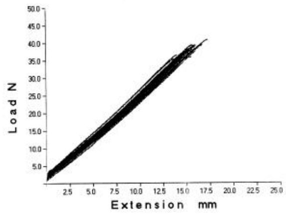

Fig. 12*: S*tress-strain diagram – wet state testing

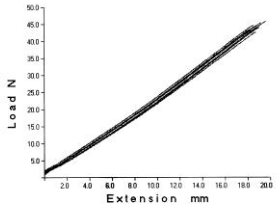

Fig. 13*: S*tress-strain diagram – loop testing after heat treatment

In order to highlight the level of characteristics of the p-aramid yarn, the yarn went through a series of operations such as winding and warping using machines from the weaving preparation within the microproduction weaving department of INCDTP. The winding operation was performed on with a speed of 6000 rpm and a tension of 0.4 cN/dtex. The warping was performed for a warping speed of 250 m/min and a folding speed of 25 m/min. 40 determinations were performed, the tests being performed within INCDTP, according to SR EN ISO 2062-2000. The diagrams of the values obtained for the wound yarns are shown in **Fig. 14** and the diagrams of the values obtained for the the warped yarn are shown in Fig. **15**.

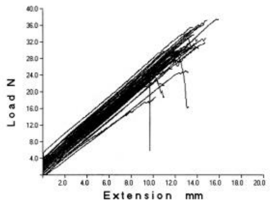

Fig. 14*: Stress/strain diagram - testing after winding operation*

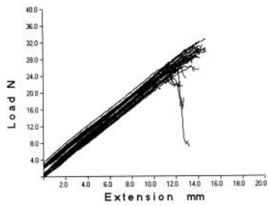

Fig. 15*: Stress/strain diagram - testing after warping operation*

3. RESULTS

The values resulting from the database processing, regarding the behavior of the para-aramid filament tested in the conditioned, wet and loop state are presented in Table 1.

Table 1: *Behavior of the para-aramid filament in conditioned state, wet state and in the loop test*

Statistical data	**conditioned state**		**wet state**		**loop test**	
	x_{med}	CV	x_{med}	CV	x_{med}	CV
breaking strength, cN	31.33	14.98	28.77	8.68	6.59	8.67
Elongation at break, %	5.10	13.05	4.34	10.39	1.87	29.06
Mechanical work, cN.cm	0.81	30.03	0.63	15.96	0.04	17.69

Analyzing the resulting data, it can be highlighted that:

- Para-aramid filaments, both in the conditioned and wet state, have a rectilinear path of the curves - similar to steel - very different from the curvilinear and continuous one of the usual textile fibers, which leads to the conclusion that there is a proportionality between resistance and elongation. rupture, so we cannot speak of a limit of elasticity, but only of a limit of rupture.
- The loop strength is 10.51% compared to a polyamide filament in which the loop strength is 80-85%, which shows that the para-aramid filament will behave like a fragile material with a low capacity to take over complex stress (stretching and compression).
- The radius of the working hand that could cause the breaking of the filament due to bending is 119 μm (for an elongation at break of 5.1% and a diameter of 12.79 μm), so the yarn can be processed on machines in the textile industry, in practice there are no working hands with such a small radius.

For the para-aramid yarn, the large number of determinations (40) regarding the tensile behavior in the conditioned state, wet state and after heat treatment at 250°C, the Grubbs test was used to eliminate the aberrant values. The calculated values of the statistic g were compared with the tabulated value, $g_{50,\ 0.95}$ = 2.956, respectively $g_{40,\ 0.95}$ = 2.866 for the verification of the null hypothesis. Absolute errors for tensile strength and elongation were determined with a statistical certainty of 95% for $t_{1-\alpha\ /\ 2;\ v}$ = $t_{0.975;\ 49}$ = 2009 and 0.975, respectively $t_{0,975;\ 39}$= 2.021. The values resulting from the tests are presented in Table 2.

Table 2: *Behavior of para-aramid yarn in conditioned state, wet state and after heat treatment at 250°C*

Statistical data	conditioned state		wet state		afret heat treatment	
	x_{med}	CV	x_{med}	CV	x_{med}	CV
Breaking strength, cN	44.70	1.25	44.37	1.95	43.19	3.02
Elongation at break, %	3.47	3.66	3.70	2.80	3.65	4.10
Initial modulus, mN/tex	0.1958	1.43	0.1882	2.55	0.778	2.42

From the analysis of the resulting data the following aspects can be highlighted:
- Applying the aberrant values test shows that the null hypothesis is not rejected, because the values calculated for the assumed minimum and maximum aberrant values are smaller than the tabulated value ($g_{calc}<g_{50;\ 0.95}$, $g_{calc}<g_{40;\ 0.95}$), so should not be excluded from the series of determinations.
- Exposure of the para-aramid yarn to 250°C did not result in significant changes in the values of breaking strength and elongation at break compared to the values recorded for the tested yarn in the conditioned state. The statistical data resulting from the mechanical stress on the machines from the weaving preparation (winding and warping) are presented in Table 3.

Table 3: *The behavior of the para-aramid yarn after the warping and winding operations*

Statistical data	after warping		after winding	
	x_{med}	CV	x_{med}	CV
Breaking strength, cN	27.95	9.78	28.83	9.00
Elongation at break, %	2.65	9.24	2.62	6.53
Initial modulus, mN/tex	0.1963	3.45	0.1944	4.68

From the data analysis it is observed that:
- the decrease of both the breaking strength and the elongation at break after the stress in the technological processes on the weaving preparation machines can be attributed to the fact that the polymer based on p-phenylene terephthalamide has more accentuated chemical creep caused by the breaking of the bonds in the molecular chain.
- the para-aramid yarn "keeps the information induced" (presents memory) by the fatigue phenomenon due to the mechanical stresses which caused changes in the structure of the filaments,

which explains reductions in breaking strength and elongation at break.

5. CONCLUSIONS

The prediction of the raw material to meet the imposed technical-functional requirements, as well as the prediction of the phenomena that take place during the rolling on landing, were made by the complex structural analysis of the main parachute canopy.

To establish the technological process line of the components, as well as of the assembly parameters and adjustment of the equipment specific to the technological flow of the fabric for the main parachute canopy there were used the results obtained after implementing a complex program for the characterization of the para-aramidic filament/yarn.

In order to carry out the structural analysis of the main parachute canopy, a specialized program was used which allowed: the determination of the unit effort on the surface of the canopy: max. 1238 daN/m^2, visualization of the distribution of the displacement vectors that allow to determine the shape of the canopy and to highlight the deformation of the canopy of the main parachute under the effect of the dynamic pressure.

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