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**Vyacheslav Astanin**[1]
**Nazarii Bondar**[2]

# DEFORMATION AND FAILURE OF THERMOPLASTIC FIBER-REINFORCED COMPOSITE EXPOSED TO DIFFERENT LIQUIDS TAKING INTO ACCOUNT TEMPERATURE

[1,2] National Aviation University
1, Kosmonavta Komarova ave., Kyiv, 03058, Ukraine
E-mails: [1]astanin@nau.edu.ua, [2]nazariibondar@gmail.com

## *Abstract*

*The thermoplastic textile-reinforced composite, known as Twintex, is investigated. Material Twintex is a woven fiberglass fabric with polypropylene fibers. The samples from this material for tensile tests according to ISO 527-4 were made by autoclave molding and then cut through water jet cutting. The samples were exposed to a hydraulic fluid AMG10 and seawater for 120 hours and then tested in accordance with the tensile standard at temperatures 273-373K. The change of elasticity modulus and strength of investigated material in considered conditions was measured. The experimental values of strength limits and elasticity modulus of investigated material at different temperatures after the influence of liquids have been obtained. Degradation of specified properties is observed depending on temperature and time of exposure comparing to the initial one. Using data of previous studies, degraded values of mechanical properties of material at various temperatures were calculated. Additionally, a change of mechanical properties of material from the temperature is taken into account. Experimental and estimated data were compared: difference between experimental and theoretical data is 6%.*

**Keywords**: composite; Twintex; strength limit and elasticity modulus; liquid; degradation

## 1. Introduction

Modern aviation and rocket structures contain a high proportion of composite materials (50% of structure weight for Boeing 787) [1]. That reduces significantly a weight of the aircraft and increases its efficiencyThere are many composite elements in a plane, such as skin, frames, spars, slats, fin, etc. [2]. The most common for aviation structures are epoxy and thermoplastic plastics reinforced by glass and carbon fabrics [1]. Therefore, the application of polymeric textile-reinforced composites is relevant in this field in our time.

Varieties of fluids are situated on board of aircraft. The greatest portion among them cover a hydraulic fluid and fuel. The outer panels of aircraft are in extended contact with external environment, which contains moisture (rainwater) with different salts. Damp and technical fluids can be accumulated on the inner surfaces of airframe. They will remain there until the next scheduled inspection. The FAR-25 aeronautical standard provide the period of damage detection (in our case, liquid accumulation) of a few intervals between inspections. During this time, a structure with damage should carry an operating load. Accumulation of fluid reduces the strength and elasticity modulus of polymeric composites [3, 4]. Caused changes can be irreversible [5] and create a damaged area in a part, that will reduce its serviceability.

Temperature has a significant effect on degradation on mechanical properties of material with the liquid [4, 6, 7]. High and low temperature may decrease as well as increase properties of properties with fluid [4, 6]. Otherwise, elasticity modulus and ultimate tensile strength depend on temperature without additional factors [7].

Therefore, combined influence of temperature and liquid on mechanical properties of material is a multifactorial and important issue.

## 2. Overview

Degradation of composite properties in any case begins from influence of the key factor. In this case, this factor will be a liquid that gets to surface of part. The liquid is adsorbed by composite surface. It penetrates into the material and causes a number of phenomena that will reduce the operational properties of part. The phenomenon of fluid adsorption by various composites is well investigated in a wide range of temperatures [8, 9].

It is shown that the key factor is a process of fluid diffusion into material.

Different approaches to describing the degradation of material properties are known [10, 11]. Agiz, Champion, and Metcalf [12] proposed a nonlinear model of corrosion fracture process, which binds the depth of damaged layer to properties of medium and time. Liddar and Whittaker suggested a similar model [13]. Denison [14] proposed a model that generalized the previous two approaches. The closest of them to descriptions of properties degradation of composites is diffusion model of degradation, because it is developed for polymer composites. They were exposed to 10% sulfuric acid and water for 90 days [12]. Another generalized approach is the logistic curve of Fairhulst [12]. A model of absorption of moisture by carbon fiber composites and polyamide films in high humidity conditions was developed on the basis of diffusion process [15].

Thus, fluid adsorption by material is well investigated, but influence of liquid on mechanical properties of composite is not fully understood. Combined influence of liquid and temperature on mechanical properties of composite is not fully understood in the same manner.

## 3. Goal of the work

Investigation of strength and elasticity modulus degradation of typical polymeric composites under combined influence of liquid and temperature.

## 4. Material and research methods

A composite reinforced by sewed glass fiber fabric with polypropylene matrix, known as Twintex, is studied in this paper. This fabric is a stitched double directional fiberglass with polypropylene fibers The fabric is sewn together to a multi-layer preform developed by Dresden Technical University [17]. The preform is formed to a plate in autoclave under vacuum bag, excess pressure 2 bars at temperature 210°C during 4 hours. Mass matrix content of composite produced in this way is 36%. Samples of "strip" type for tensile testing according to standard ISO 527-4 were cut by water jet processing from the plate. Tabs from Twintex were glued to samples using an epoxy adhesive.

Basic mechanical properties of Twintex have been predefined and taken from [18] Determination of these properties was performed in accordance to DIN EN ISO 527 and DIN EN ISO 14129 standards for tensile testing on Instron 8801 test machine. Properties of the material are given in Table . These properties were used for numerical calculations below.

*Table*

**Basic mechanical properties of Twintex**

| Parameter | Unit | Value |
|---|---|---|
| Elasticity modulus (warp direction) $E_1$ | GPa | 23 |
| Elasticity modulus (weft direction) $E_2$ | GPa | 22.5 |
| Poisson ratio in plane $\nu_{12}$ | - | 0.13 |
| Ultimate tensile strength (warp direction) $\sigma_{B1}$ | MPa | 433 |
| Ultimate tensile strength (weft direction) $\sigma_{B2}$ | MPa | 484 |

To establish combined fluid and temperature influence on changing of mechanical properties of composite the following experiment was performed. Samples for tensile testing were exposed to AMg10 and seawater for 120 hours (duration and fluid types selection will be explained below). These samples with adsorbed fluids were tested on tension according to standard ISO 527-4 at temperature 273-373K. Obtained results were verified by numerical calculation similar to experiment. The calculation was performed according to method described in [19].

This allows us to establish and numerically describe a behavior of typical polymeric composites under influence of liquid and temperature.

## 5. Results

According to results of the previous investigation [19], the following was established:

1. Active adsorption of various types of fluids by composite material is observed in the first 200 hours of exposure in a liquid.
2. AMg10 (simulates fuel and hydraulic fluid) and seawater (simulates rainwater with different salts) have the greatest probability of contamination of frame parts.
3. Degradation of material mechanical properties is proportional to amount of liquid in it.
4. The greatest impact on thermoplastic glass fiber composite have AMG10 and seawater.

Thus, AMG10 and seawater containing 3.5% salt and Twintex were selected for research. Prepared samples for tensile testing were exposed to those liquids for 120 hours.Duration of exposure is related to half the amount of adsorbed liquid from maximal possible in considered condition. Then these samples were tested according to ISO 527-4 standard at temperature 273-373K. Ultimate tensile strength and elasticity modulus were determined during tests. Test results were normalized relative to the initial properties (Table 1) using formulas (1)-(2) and are shown on Fig. 1:

$$\overline{\sigma_B} = \frac{\sigma'_B}{\sigma_{B0}}; \qquad (1)$$

$$\bar{E} = \frac{E'}{E_0}, \qquad (2)$$

where $\sigma_{B0}$ – initial ultimate tensile strength; $E_0$ – initial elasticity modulus; $\overline{\sigma_B}$, $\sigma'_B$ – relative and absolute effected ultimate tensile strength; $\bar{E}$, $E'$ – relative and absolute effected elasticity modulus.

In this case, it is necessary additionally to take into account a change of elasticity modulus and strength from temperature without properties degradation. Elasticity modulus of epoxy fiberglass composite is close to Twintex by reinforcement. Elasticity modulus at different temperatures for epoxy fiberglass composite is given in report data for Twintex - [17, 18]. According to the data, dependence of elasticity modulus on temperature is not significant in the temperature range -50:100°C and can be described by linear law in all cases. Therefore, available data is sufficient to form dependence of elasticity modulus on temperature in noted range

$$E = E_0(-3{,}38T^2 \times 10^{-5} + 0.0184T - 1.4854) \qquad (3)$$

where $E$ – elasticity modulus in GPa, $T$ – temperature in K. In the same way using data for strength of Twintex at different temperatures [17, 18] and epoxy fiberglass composite [20], the change of strength of Twintex can be described quite well by linear dependence:

$$\sigma_B = \sigma_{B0}(-0{,}026T + 1.81)\,, \qquad (4)$$

where $\sigma_B$ – ultimate tensile strength in MPa. Using dependencies for describing degradation of relative strengthand relative elasticity modulusunder influence of liquid [19] and formulas (1)-(4), theoretical curves were calculated for obtained experimental data. The experimental and calculated data are shown on Fig. 1.

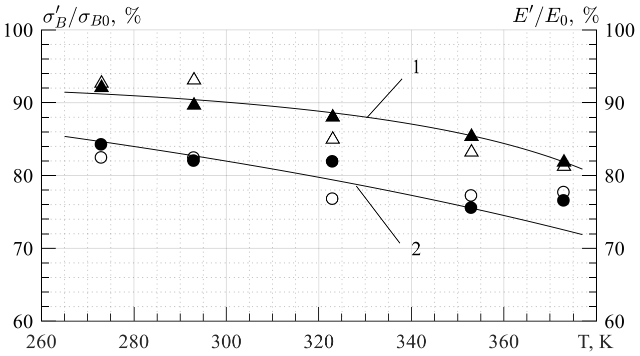

Fig.1. Experimental (points) and calculated (curves) dependences of relative strength (○●, 2) and relative elasticity modulus (Δ▲, 1) of Twintex from temperature after exposure in AMg10 (light points) and seawater (dark points) for 120 hours

Calculated curves quite well describe experimental data. That confirms correctness of used approach [19]and indicates the following: material properties depend on internal stresses caused by swelling pressure. Internal stresses increase wincreasing of temperature, which leads to decreasing of material mechanical properties, and - on the contrary. Mechanical properties are additionally changed due to influence of only temperature (formulas (3)-(4)). However, the key factor for calculating of mechanical properties of material with liquid is internal stresses, which cause degradation of material properties and affect on material mechanical properties at temperature.

## 6. Conclusions

1. Material mechanical properties depend on the amount of adsorbed liquid. It agrees with results of work [19].
2. Effect of AMg10 and seawater on Twintex leads to the same change of material mechanical properties under equal conditions. It agrees with data from [19].
3. Temperature variation affects the variation of internal stresses in material caused by swelling pressure. That results the changes of material mechanical properties. Temperature increasing leads to decreasing of material mechanical properties, and on the contrary.

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**В.В. Астанін[1], Н.В. Бондар[2]**

## Деформування та руйнування термопластичного волокнистого композиту при впливі різних рідин з урахуванням температури

[1,2]Національний авіаційний університет, просп. Космонавта Комарова 1, Київ, Україна, 03058
E-mails: [1]astanin@nau.edu.ua, [2]nazariibondar@gmail.com

Досліджується термопластичний текстильно-підсилений композит, відомий під назвою Twintex. Матеріал Twintex є прошитою склотканиною із поліпропіленовими волокнами. Зразки з цього матеріалу для випробувань на розтяг згідно зі стандартом ISO 527-4 виготовлялись автоклавним методом формування та потім вирізались шляхом водоструминного різання. Зразки витримували у гідравлічній рідині АМг10 та морській воді протягом 120 годин і потім випробовували згідно вказаного стандарту на розтяг за температур 273-373К. Вимірювали зміну модуля пружності та границі міцності досліджуваного матеріалу у розглянутих умовах. Отримано експериментальні значення границь міцності та модулів пружності досліджуваного матеріалу при різних температурах після впливу рідин. Спостерігається деградація вказаних характеристик міцності залежно від температури та часу витримки порівняно із початковими. Використовуючи дані попередніх досліджень розраховано деградовані значення механічних характеристик матеріалу при різних температурах. Додатково враховано зміну механічних характеристик матеріалу від температури. Порівняно експериментальні та розрахункові дані: розбіжність експериментальних та теоретичних даних складає 6%.

**Ключові слова**: композит; Twintex; границя міцності та модуль пружності; рідина; деградація

**В.В. Астанин[1], Н.В. Бондар[2]**

## Деформирование и разрушение термопластичного волокнистого композита при воздействии различных жидкостей с учетом температуры

[1,2]Национальний авиационный университет, просп. Космонавта Комарова 1, Киев, Украина, 03058
E-mails: [1]astanin@nau.edu.ua, [2]nazariibondar@gmail.com

Исследуется термопластичный текстильно-усиленный композит, известный под названием Twintex. Материал Twintex является прошитой стеклотканью с полипропиленовыми волокнами. Образцы из этого материала для испытаний на растяжение согласно стандарту ISO 527-4 изготовлялись автоклавным методом формирования и затем вырезались путем водоструйной резки. Образцы выдерживали в гидравлической жидкости АМг10 и морской воде в течение 120 часов и затем испытывали согласно указанному стандарту на растяжение при температурах 273-373К. Измеряли изменение модуля упругости и предела прочности исследуемого материала в рассматриваемых условиях. Получены экспериментальные значения пределов прочности и модулей упругости исследуемого материала при различных температурах после воздействия жидкостей. Наблюдается деградация указанных характеристик прочности в зависимости от температуры и времени выдержки по сравнению с начальными. Используя данные предыдущих исследований рассчитаны деградированные значения механических характеристик материала при разных температурах. Дополнительно учтено изменение механических характеристик материала от температуры. Сравнены экспериментальные и расчетные данные: расхождение экспериментальных и теоретических данных составляет 6%.

**Ключевые слова:** композит; Twintex; предел прочности и модуль упругости; жидкость; деградация

**Vyacheslav Astanin.** Dr. Sci. (Engineering)
Professor of Mechanics Department, National Aviation University.
Education: Tashkent State University (1969)
Research area: strength of composites
Publications: 78
E-mail: astanin@nau.edu.ua

**Nazarii Bondar**. Research assistant
Mechanics Department, National Aviation University.
Education: National Aviation University (2015)
Research area: strength of composites
E-mail: nazariibondar@gmail.com