Ministry of Education and Science of Ukraine
National Aerospace University
"Kharkiv Aviation Institute"

Department of composite structures and aviation materials (№ 403)

**APPROVED**
Head of educational program
_________________ M. Shevtsova
«____» ________________ 2020

# GRADUATING PROGRAM OF THE DISCIPLINE

Strength of composite structures
(title of discipline)

**Field of Study**: 13 «Mechanical engineering»
(code and title of the field of study)

**Program Subject Area**: 134 «Aerospace engineering»
(code and title of the program subject area)

**Educational program**: Design and manufacturing of composite structures
(title of educational program)

**Mode of study:** Full-time

**Degree**: Bachelor

Kharkiv 2020

Educational program «**Strength of composite structures**» for students majoring in **134 «Aerospace engineering»**, educational program **«Design and manufacturing of composite structures»**.

28.08.2020 – 10 pages.

Developed by:
Associate professor of the Department of composite structures and aviation materials, PhD

_______________ P. Gagauz
(signature)

The educational program was considered at the meeting of the Department of composite structures and aviation materials (№403), protocol № 1 dated 31.08.2020

Head of the Department of composite structures and aviation materials _______________ M. Shevtsova
(signature)

## 1. Discipline syllabus

<table>
<tr><td rowspan="2">Indicator</td><td rowspan="2">Field of study,<br>subject area,<br>educational program,<br>degree</td><td colspan="2">Characteristics<br>of the discipline</td></tr>
<tr><td colspan="2">Full-time</td></tr>
<tr><td>Credits – 4</td><td rowspan="17">Field of study<br>13 Mechanical engineering<br>(code and title)<br><br>Subject area<br>134 «Aerospace engineering»<br>(code and title)<br><br>Educational program<br>«Design and manufacturing of composite structures»<br><br>Degree<br>bachelor</td><td colspan="2">Training cycle (optional)</td></tr>
<tr><td>Modules – 2</td><td colspan="2">Academic year</td></tr>
<tr><td>Content modules – 4</td><td colspan="2">2020 / 2021</td></tr>
<tr><td rowspan="4">Individual task<br>______________<br>______________<br>(title)</td><td colspan="2">Semester</td></tr>
<tr><td>7-th</td><td>8-th</td></tr>
<tr><td colspan="2">Lectures[2)]</td></tr>
<tr><td>32 hours</td><td>–</td></tr>
<tr><td rowspan="3">Total hours – 120</td><td colspan="2">Practices, seminars[2)]</td></tr>
<tr><td>24 hours</td><td>–</td></tr>
<tr><td colspan="2">Laboratory[2)]</td></tr>
<tr><td rowspan="7">Weekly hours for full-time study[1)]:<br>- classroom – 3,5<br>- individual student work – 4</td><td>–</td><td>-</td></tr>
<tr><td colspan="2">Individual work</td></tr>
<tr><td>64 hours</td><td>–</td></tr>
<tr><td colspan="2">Individual tasks</td></tr>
<tr><td>–</td><td>–</td></tr>
<tr><td colspan="2">Type of control</td></tr>
<tr><td>exam</td><td>–</td></tr>
</table>

**Note:**
[1)] The ratio of the classroom hours to hours of the independent and individual work for full-time education is 56/64.
[2)] Classroom load can be reduced or increased by one hour depending on the schedule.

## 2. The purpose and objectives of the discipline

**The purpose of the study:** the formation of students' professional profile knowledge and practical skills in the application of physical and mathematical models in special problems of mechanics of composite materials (CM) and composite structures; acquaintance of students with models of definition of limiting bearing capacity of composite designs, and also with bases of linear mechanics of destruction.

**Objectives:** to study methods for calculating physical and mechanical properties for composites with asymmetric thickness of the package, existing models of degradation of KM properties to study the gradual failure of composite structures, the basics of designing structures for long-term strength and methods of experimental study of the fracture process.

**Learning outcomes:** As a result of studying the discipline the student must

**know:**

- methods for predicting the physical and mechanical characteristics of composites with an asymmetric package structure;
- methods for determining the stress-strain state in plates with an asymmetric structure of the package;
- strength criteria and methods for calculating the strength limits of composite structures using models of gradual failure;
- methods of studying the resistance of composite structures to fatigue load;
- methods for determining the critical size of defects and the life of structural elements;

**be able to:**

- determine the deformation properties and strength characteristics of composites with an arbitrary package structure;
- evaluate the ultimate load-bearing capacity of composite structures under static and fatigue loads;
- apply mathematical methods of fracture mechanics in solving applied engineering problems, namely to estimate the magnitude of critical loads, the allowable size of the defect, the number of load cycles before failure, etc.;

**has an idea of:**

- basic terms, concepts and methods of fracture mechanics;
- ways to increase the crack resistance of structural elements.

## 3. Discipline program

**Module 1.**

**Submodule 1. Special problems of mechanics of composite structures.**

**Topic 1. Mechanics of composites with asymmetric lay-ups.**

Physical law for laminated composites with arbitrary package structure. Determining the stiffness characteristics of the package of composite layers. The concept of structure, reinforcement schemes and their influence on the stiffness characteristics of laminated composites. Some cases of reinforcement schemes. Determination of effective elastic characteristics. Influence of temperature loading on composite deformation with arbitrary package structure, effective coefficients of thermal expansion.

**Topic 2. The strength of the KM with asymmetric laying of layers along the thickness of the package.**

Calculation of strength characteristics of composites with asymmetric lay-ups. Problems of transverse bending and stability of plates with asymmetric structure.

**Submodule 2. Progressive failure analysis of composite structures.**

**Topic 3. Load-bearing capacity of composite structures under static loading.**

Difficulties in predicting and assessing the strength of reinforced inhomogeneous materials and the main approaches to solving these problems. Forms of composite fracture. Theories of strength of orthotropic materials. Phenomenological criteria of strength, their classification, the most common strength criteria for the calculation of composite structures. Degradation of composite properties with gradual destruction. The effect of the destruction of a single layer on the overall stiffness and strength of the layer package. Models of fixed stress, gradual and instantaneous unloading, their variations. Other models of gradual fracture (Brinson model, model of displaced cracks). Methods for calculating the ultimate bearing capacity of the composite without taking into account the destruction of the matrix. Hart-Smith criterion (truncated maximum deformations).

**Topic 4. Load-bearing capacity of composite structures under fatigue load.**

Basic concepts of fatigue fracture mechanics. Amplitude and scope of the load cycle, cycle frequency, cycle asymmetry coefficient, endurance limit of the material. Their relationship. Features of fatigue deformation and destruction of composites. Degradation of composite properties under fatigue load. Estimation of resistance of a composite design to fatigue loading by Hashin's criterion. Experimental determination of fatigue strength coefficients.

**Modular control №1.**

**Module 2.**

**Submodule 3. Stress concentration.**

**Topic 5. Coefficients of stress concentration in isotropic plates.**

Perturbation of the stress field around local changes in the geometry and rigidity of the structure: cutouts, holes, reinforcements, thickenings, etc. The concept of stress concentration. Theoretical and effective stress concentration coefficients, sensitivity of the material to stress concentration. Kirsch's solution for the distribution of stresses around a circular hole in an isotropic plate. Kolosov – Inglis solution for an elliptical hole in an isotropic plate.

**Topic 6. Coefficients of stress concentration in composite plates.**

Lechnitsky's formula for an orthotropic plate with a cylindrical hole. Whitney and Nuismer solutions for stress distribution around a cylindrical hole in a composite plate and for determining the strength limits of a plate with a hole. The criterion for estimating stresses at a point and the criterion of averaged stresses. Influence of the hole size on stress concentration factor, scale factor. Using the Whitney and Nuismer criteria to calculate composite plates with a crack.

**Submodule 4. Fundamentals of linear fracture mechanics.**

**Topic 7. Basic concepts of fracture mechanics.**

Subject and object of fracture mechanics. Theoretical and real strength of solids. The first model of a body with a crack (Griffiths crack). The stress state at the crack tip. The principle of the "microscope". Three types (shapes) of cracks. Stress intensity coefficients. Methods for calculating stress intensity coefficients in elastic bodies under different load conditions. The principle of superposition of solutions. Stress intensity factor in DCB-sample. Force criterion of local destruction. The flow of energy to the top of the crack. Energy criterion of local destruction. Equivalence of power and energy criteria. Stability and instability of crack growth.

**Topic 8. Mechanics of elastic-plastic fracture.**

The structure of the end of a semi-infinite elastic-plastic crack. The concept of quasi-brittle destruction. Irwin's correction for plastic deformation. Other criteria for local destruction. Coupling forces. Leonov – Panasyuk – Dugdale model. Modification in the Dugdale model. Invariant J-integral of Eshelby – Cherepanov – Rice. Experimental methods for determining the fracture toughness (crack resistance) of the material.

**Topic 9. Mechanics of fatigue failure.**

Features of fatigue deformation and destruction. Multicycle and low cycle fatigue. Growth of cracks at cyclic loading. Empirical formula of Paris. Theoretical dependences of fatigue crack growth. Fatigue durability. Plastic zones near the top of the crack during overload and partial unloading. Acceleration and inhibition of fatigue cracks. Structural and technological methods of crack inhibition.

**Modular control №2.**

## 4. Discipline structure

| **Modules and topics** | **Hours** | | | | | |
|---|---|---|---|---|---|---|
| | **total** | **including** | | | | |
| | | **lec** | **prac** | **lab** | **indiv** | **indep** |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| **Module 1.** | | | | | | |
| **Submodule 1. Special problems of mechanics of composite structures.** | | | | | | |
| Topic 1. Mechanics of composites with asymmetric lay-ups. | 16 | 4 | 6 | – | – | 6 |
| Topic 2 The strength of the KM with asymmetric laying of layers along the thickness of the package. | 12 | 2 | 2 | – | – | 8 |
| Total for submodule 1 | **28** | **6** | **8** | – | – | **14** |
| **Submodule 2. Progressive failure analysis of composite structures.** | | | | | | |
| Topic 3. Load-bearing capacity of composite structures under static loading. | 14 | 4 | 4 | – | – | 6 |
| Topic 4. Load-bearing capacity of composite structures under fatigue load. | 16 | 4 | 2 | | | 10 |
| Total for submodule 2 | **30** | **8** | **6** | – | – | **16** |
| **Module 2.** | | | | | | |
| **Submodule 3. Stress concentration.** | | | | | | |
| Topic 5. Coefficients of stress concentration in isotropic plates. | 10 | 2 | - | – | – | 8 |
| Topic 6. Coefficients of stress concentration in composite plates. | 22 | 6 | 6 | | | 10 |
| Total for submodule 3 | **32** | **8** | **6** | – | – | **18** |
| **Submodule 4. Fundamentals of linear fracture mechanics.** | | | | | | |
| Topic 7. Basic concepts of fracture mechanics. | 8 | 4 | - | – | – | 4 |
| Topic 8. Mechanics of elastic-plastic fracture. | 10 | 2 | 2 | | | 6 |
| Topic 9. Mechanics of fatigue failure. | 12 | 4 | 2 | | | 6 |
| Total for submodule 4 | **30** | **10** | **4** | – | – | **16** |
| **Total** | **120** | **32** | **24** | – | – | **64** |

## 5. Practical classes

| № | Title | Hours |
|---|---|---|
| 1 | Stiffness terms of non-symmetric laminates | 2 |
| 2 | Effective elastic properties of non-symmetric laminates | 2 |
| 3 | Thermal effects in non-symmetric laminates | 2 |
| 4 | Strength analysis of non-symmetric laminates | 2 |
| 5 | Strength analysis of composite laminate by ply discount model | 2 |
| 6 | Strength analysis of composite laminate by truncated maximum strain criterion | 2 |
| 7 | Composite laminates fatigue analysis by Hashin – Rotem criterion | 2 |
| 8 | Stress distribution around hole in composite panel | 2 |
| 9 | Effect of laminate configuration on stress concentration and load-bearing capacity of composite panel | 2 |
| 10 | Scale factor in stress concentration analysis | 2 |
| 11 | Computation of limit stresses and crack limit length with respect to local plastic deformations | 2 |
| 12 | Fatigue analysis by Paris law | 2 |
| | **Total** | **24** |

## 6. Independent work

| № | Title | Hours. |
|---|---|---|
| 1 | Mechanics of composites with asymmetric lay-ups (Topic 1) | 6 |
| 2 | The strength of the KM with asymmetric laying of layers along the thickness of the package (Topic 2) | 8 |
| 3 | Load-bearing capacity of composite structures under static loading (Topic 3) | 6 |
| 4 | Load-bearing capacity of composite structures under fatigue load (Topic 4) | 10 |
| 5 | Coefficients of stress concentration in isotropic plates (Topic 5) | 8 |
| 6 | Coefficients of stress concentration in composite plates (Topic 6) | 10 |
| 7 | Basic concepts of fracture mechanics (Topic 7) | 4 |
| 8 | Mechanics of elastic-plastic fracture (Topic 8) | 6 |
| 9 | Mechanics of fatigue failure (Topic 9) | 6 |
| | **Total** | **64** |

## 7. Teaching methods

Conducting lectures, practical classes, individual consultations (if necessary), independent work of students on the materials published by the department (methodical manuals), calculation work.

## 8. Control methods

Carrying out of current control in the form of performance of practical works, written modular control, control of performance of settlement work, final control in the form of examination.

## 9. Evaluation criteria and points distribution

**Quantitative evaluation criteria (distribution of points).**

| Components of educational work | Points for one class (task) | | Number of classes (tasks) | Total number of points | |
|---|---|---|---|---|---|
| | min | max | | min | max |
| **Module 1** | | | | | |
| Practical classes | 3 | 5 | 7 | 21 | 35 |
| Modular control №1 | 6 | 10 | 1 | 6 | 10 |
| | | | Total | 27 | 45 |
| **Module 2** | | | | | |
| Practical classes | 3 | 5 | 5 | 15 | 25 |
| Homework * | 12 | 20 | 1 | 12 | 20 |
| Modular control №2 | 6 | 10 | 1 | 6 | 10 |
| | | | Total | 33 | 55 |
| | | | **Total for semester** | **60** | **100** |
| * Mandatory control work | | | | | |

The semester control (exam) is carried out in case of refusal of the student from points of current testing and in the presence of the admission to examination (performance and protection of settlement work). During the semester exam the student has the opportunity to get a maximum of 90 points. The exam is conducted in the form of computer testing. The set of control tasks consists of 6 questions on the above Topics (3 questions from each module). The maximum number of points for each correct answer to the test task is 15 points.

**Qualitative evaluation criteria (required amount of knowledge and skills).**

The required amount of knowledge to obtain a positive assessment:
- methods for predicting the physical and mechanical characteristics of composites with an asymmetric package structure;
- methods for determining the stress-strain state in plates with an asymmetric structure of the package;
- strength criteria and methods for calculating the strength limits of composite structures by models of gradual failure;
- methods of research of resistance of composite designs to fatigue loading;
- methods for determining the critical size of defects and the life of structural elements.

The required amount of skills to obtain a positive assessment:
- determination of deformation properties and strength characteristics of composites with arbitrary package structure;
- evaluation of the ultimate bearing capacity of composite structures under static and fatigue loads;
- application of topical methods of fracture mechanics in solving applied engineering problems, namely to estimate the magnitude of critical loads, the allowable size of the defect,

the number of load cycles before failure, etc.

**Criteria for evaluating student work during the semester.**

**Satisfactory (60… 74).** Show a minimum of knowledge and skills. Pass all modular tasks. Be able to independently calculate the stiffness characteristics of composites with an arbitrary package structure and determine the ultimate bearing capacity of layered KM.

**Good (75… 89).** Firmly know the minimum, pass all modular tasks and additional extracurricular independent work. Solve applied engineering problems based on the static and long-term strength of layered KM under complex loads using a computer.

**Excellent (90… 100).** Pass all control measures and additional extracurricular independent work with a grade of "excellent". Thoroughly know the information on all topics and be able to apply it.

## Assessment scale: national and ECTS

<table>
<tr><th>The sum of points for all types of educational activities</th><th>ECTS</th><th>Score by a national scale</th></tr>
<tr><td>90 – 100</td><td>A</td><td>excellent</td></tr>
<tr><td>83 – 89</td><td>B</td><td rowspan="2">good</td></tr>
<tr><td>75 – 82</td><td>C</td></tr>
<tr><td>68 – 74</td><td>D</td><td rowspan="2">satisfactory</td></tr>
<tr><td>60 – 67</td><td>E</td></tr>
<tr><td>1 – 59</td><td>FX</td><td>unsatisfactory;<br>allows additional attempts</td></tr>
</table>

## 10. Methodical support

Methodical instructions for performance and tasks for practical work, as well as for calculation work.

## 11. Recommended Books


1. Barbero E.J. Introduction to Composite Materials Design, 3rd ed., 2017. - 570 p. ISBN-13: 978-1-1381-9680-3
2. Lechnitsky S. Anisotropic plates, 1968 - 534 p. ISBN-13: 978-0-677-20670-7
3. Jones R.M. Mechanics of Composite Materials, 2nd ed., 1999 - 538 p. ISBN-13: 978-1-560-32712-7
4. Pilkey W.D., Pilkey D.F. Peterson's Stress Concentration Factors, 3rd ed., 2008. - 560 p. ISBN-13: 978-0-470-04824-5
5. Anderson T.L. Fracture Mechanics: Fundamentals and Applications, 4th ed., 2017. – 706 p. ISBN-13: 978-1-498-72813-3


## 12. Information resources

Website of the department **http://k403.khai.edu**