UNIVERSAL RESEARCH AND DEVELOPMENT ENTERPRISE (URDE)

PRESENTS

BASALT IN AEROSPACE AND SHIPBUILDING INDUSTRIES

Composite materials become more and more used in mechanical engineering and also in aviation technological processes and missile mechanics. As a part of construction composites, felts are the main component(70-80 % of total amount) and guarantee their fracture strength characteristics. Reinforcing felts price as a part of composites in general determines their value. Glass, chemical, carbon and basalt continuous fibers are used to produce composites. Comparative characteristics and value of CF(continuous fibers) are given in the Table 1.

In mechanical engineering cheap glass fibers are used in general. Carbon and aramid fibers are used for the most important parts, where it is economically advantageous to use expensive reinforcing materials (fibers). Technical and economic analysis shows that BCF and BCF based materials (rowing's, fibers, prepregs, nonwoven materials) are the most convenient to be used in composites. Due to its price - characteristics combination BCF are the most prospective materials to use in mechanical engineering and especially in aviation branch.

Serious crisis takes place in airborne vehicles manufacturing world. Aircraft basic elements (fuselage, wings, their main elements and structures) are manufactured of aluminum alloys. Technologies of Second World War are used, for example riveted joints. Bridges construction engineers refused to use riveted constructions long ago, but aircraft engineers use them even nowadays.

Heavy aircraft structures need to have more powerful engines and fuel reserves to fly. As a result, the weight of transportable payload (passengers, baggage, cargo) is insignificant in comparison with the take-off weight of the aircraft. For long-haul passenger aircraft like Boeing 777, Airbus 350, the percent of useful weight is 12-15%, for big aircraft like Boeing 747-8 and Airbus 380 - 15-17%. It is obvious that it is possible to reduce the weight of the airframe design by applying composites. This was done for Boeing 777, A320-321; the proportion of composites from their weight was 9% and 20%, respectively. The percent of composites in the design of the most modern Boeing 787 and A 350 has reached 50 and 52%. However, in the vector of widespread use of composites, there are limitations and restrictions on their characteristics and cost. Fiberglass characteristics do not allow to use the composites based on them for exterior structures and carbon fibers are too expensive.

Cost of aircraft made of traditional aluminum alloys structures with addition of some composite elements (interior paneling, fairings, wing tips, part of empennage, etc.) has already reached the highest level. For example, the cost of Boeing 737, depending on the modifications for 160-190 passengers is $ 70-90 million. The use of composite materials based on expensive carbon fibers significantly increases the cost of aircraft. Boeing 787 (for 190-320 passengers) cost is 250-290 million dollars. Further cost increase of the aircraft is simply impossible. Airlines simply cannot recoup the purchased aircraft.

The use of composite materials based on basalt continuous fibers (BCF) can be the way out of the situation in the aerospace industry. Modern technologies ensure the production of BCF with high strength characteristics at the carbon fibers level and low prime cost of industrial production of BCF, at the level of fiberglass.

BCF has high performance characteristics. The chemical, thermal and environmental resistance of BCF are well known [1]. Characteristics and cost of BCF allow to create basic aircraft designs on the basis of BCF composites as well as individual elements that are currently produced from carbon and fiberglass composites. Currently, the development of BCF technology and manufacturing equipment can provide solutions to two main tasks: significant reduction of weight and cost of aircraft constructions.

Following factors are the main to use BCF in aerospace industry:

1. Basalt fibers (BF) are manufactured on the basis of prime volcanogenic basalt rocks with high natural thermal properties and chemical resistance. That’s why BF possess the primary durability, resistance to aggressive environments, high thermal and heat insulation properties and also a low hygroscopicity. This determines operating properties of BF based materials: Durability characteristics, shock strength, resistance to natural environment factors, high temperatures, aggressive environments, stability to vibrations.

2. Reached level of technology and equipment makes it possible to produce BCF at a low production cost on the level of fiberglass with the structural capabilities of carbon and aramid fibers. This allows to manufacture BCF based materials at much lower cost and to significantly reduce price of composite materials and parts. To date, a very gross experience is obtained in application of BF in mechanical engineering, automotive industry, shipbuilding, carriage building, power engineering, construction, and road construction. BCF application works in aerospace industry were carried out before, but now they are at a very high level.

3. BCF complex tests have shown that they possess some characteristics which make it possible to create BCF based materials with high strength and operating characteristics. BCF has the best quality - to - price ratio in comparison with other fibers used to manufacture reinforcing materials and composites.

4. Large experience obtained in creation of industrial plants of reinforcing BCF and BCF based materials on 9 factories, including gross plant for aerospace industry [2].

BCF Main advantages and characteristics

1. Relatively high fibers disruptive specific strength, 2-2,5 times more that the alloy steel and 1,4-1,5 times more than the fiberglass. BCF disruptive specific strength data is represented in table 2 (at a different thickness of primary fibers)[3].

2. High resistance to corrosion and chemicals in aggressive environments: saline solutions, acids, alkalis. Basalt fibers have a unique chemical resistance. This property of basalt fibers open wide possibilities and perspectives of their application in structures that operate tens of years under the moisture attack, de-icing substances, saline solutions, acid and alkalis environment. Basalt-plastics replace steel rebar, parts and structures that corrode under the influence of sea water and chemical environments.

3. Basalt fibers possess high thermal stability. Materials that can long term operate under high temperatures are manufactured on BCF basis. BCF thermal diapason is from -200(for cryogen instruments) to 600^{o}C . At a long time operating diapason of temperature -100^{o}C to +400^{o}C BCF almost completely retains its properties. At this thermal change of BCF composites length is 1,5 - 2,5 %. High heat-resistant BCF with 900^{o}C operating temperature are also possible.

4. High thermal and sound insulation characteristics [3].

5. Low hygroscopicity - 6-8 times lower than fiberglass. That's why thermal and sound insulation materials based only on basalt fiber are applied in aircraft and shipbuilding.

6. High resistance to fluctuating loads. BCF based rods (F 10mm) are used for more than 14 years in flour mill shaking sieves suspension. BCF are used to produce high pressure cylinders designed for dozens of thousands of refueling cycles. Under the influence of fluctuating loads BCF composites doesn't have fatigue distresses - cracks and other signs of destruction. This is more than important to create reliable aircraft structures.

7. High shock strength of BCF based composites. BCF are used to create shockproof road guardrails, bumpers, and bulletproof vests. Due to resilient modulus of BCF fiber basis in the shock moment cracks doesn't appear and full destruction doesn't occur in the structure.

8. Close compatibility with other materials: metals and plastics. Application of strong adhesive-bonded joints instead of rivets and welding. This opens a wide manufacturing perspective of the gross variety of combined composite materials: honeycomb core structures, reinforced plastics, panels, main beams, coverings, fuselage etc. Possibility of manufacturing of composite parts with gelcoats - aerodynamically well-made and reliable exterior structures.

9. BCF materials and parts operating characteristics, high resistivity to aggressive environments, long operating terms.

10. Possibility of BCF materials manufacturing using different technologies: pultrusion, winding, molding, vacuum molding, blanking, spraying and other cold technologies. Prospective branch is the production of BCF composites on the basis of prepregs (binder pre-impregnated roving, fabrics, non-woven materials, basalt paper). Prepregs use makes it possible to manufacture composite materials of high quality and durability, high strength with low weight.

11. Low prime cost of BCF production. Price-to-characteristics ratio of BCF comparing with other fibers is the preferable.

12. BCF and BCF based materials manufacturing establishment for aerospace industry doesn't need any significant investments. BCF industrial manufacturing are established at a module basis with the gradual increasing of production volumes[4].

Characteristics (1-10) and low prime cost of production open a wide range of BCF materials application possibilities. We have a very gross experience in producing of a whole range of materials and products for the aerospace industry.

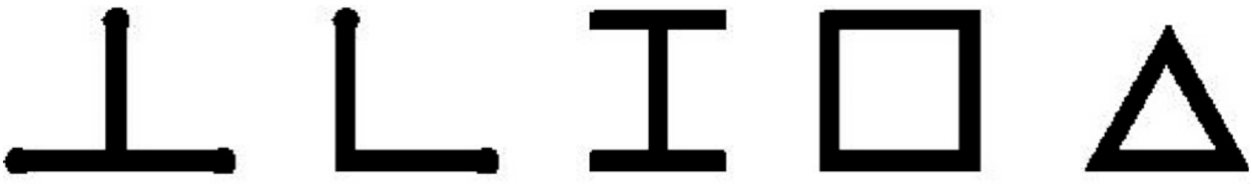
MAIN LINES OF BCF APPLICATION IN AEROSPACE INDUSTRY

Thermal and sound insulation materials based on basalt super thin fibers and needled fabrics. Thermal and sound insulation mats (TM-19-20, ATM-10C-20, ATM 10K-20) based on basalt super thin fibers due to their high sound insulation characteristics, low hygroscopicity have been applied for many years in aircraft, shipbuilding, gas transmission services based on aero engines.

COMPOSITE MATERIALS AND PARTS

1. Composite structural shapes and side members.

Composite structural shapes are made of BCF roving on pultrusion lines. Manufacturing and shapes testing works are carried out for aircraft and rocket and missile engineering. Manufacturing of reinforcing longitudinal side members: stringers, angles, channels, I-beams, pipes, square pipes, complex structure shapes (pic. 1 - BCF roving based profiles).



Picture 1.

BCF based profiles have a good resistance to fluctuating loads. Elongation at temperature change is 1,5 - 2,5% , elongation at tension fracture in not more than 3%. Profiles junction together, with other elements and with coverings is performed with glue joints.

To date, rebar, pipes, complex structure profiles, cable-wire ropes are manufactured of BCF rovings.

Full-size tests of basalt-plastic rebar (chemical resistance tests, resistance to freezing/melting) are performed in Reinforced Concrete research institute and Road Construction research institute. We have developed recommendations for use of basalt-plastic rebar in construction, state standards have been adopted: Ukrainian all-Union state standard, Russian all-Union state standard and PRC Union state standard, EU and USA standards are in development stage.

In PRC government program №863 "Basalt continuous fiber and BCF composite materials" was adopted to establish factories and a wide range of BCF materials application in industrial branches, including aerospace industry.

2. Composite load-bearing profiles.

Composite load-bearing profiles are manufactured of BCF roving and prepreg based roving, strips. Equipment for manufacturing of composite load-bearing profiles of mountainous territory bridges, light pillars and electricity transmission towers.

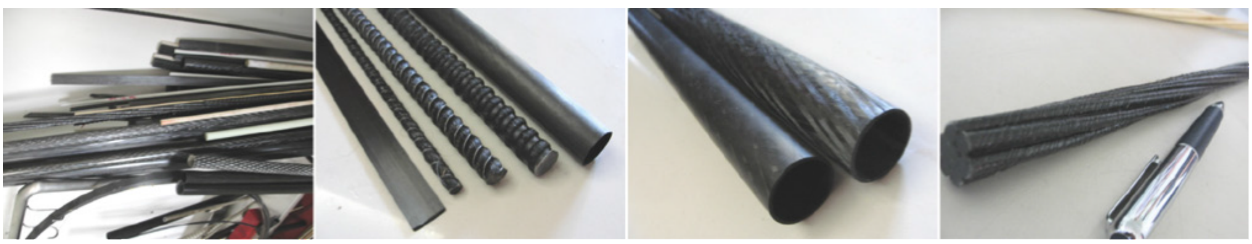
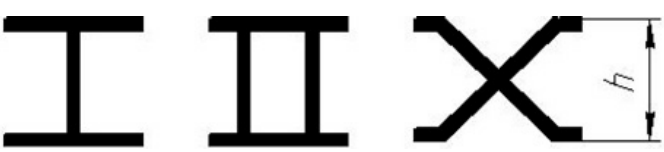
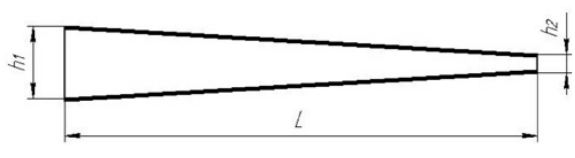


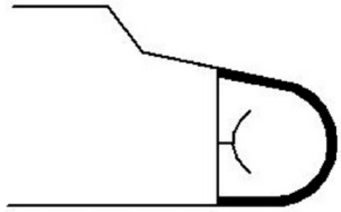
Photo 1. Longitudinal profile materials made of BCF roving, rebar, pipes, wire rope



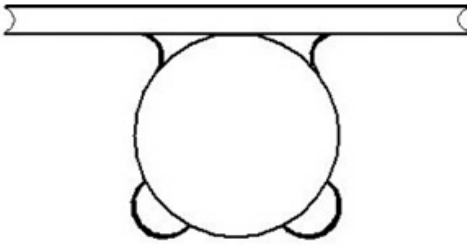


Variable cross-section profile

Load-bearing beams



Radiodetector fairing



Undercarriage bay fairing, wing butting curves

To add extra strength to load-bearing profiles and longitudinal panels, special unidirectional roving fabric was developed (longitudinal reinforcing element, flat surface rebar, photo 2.2).

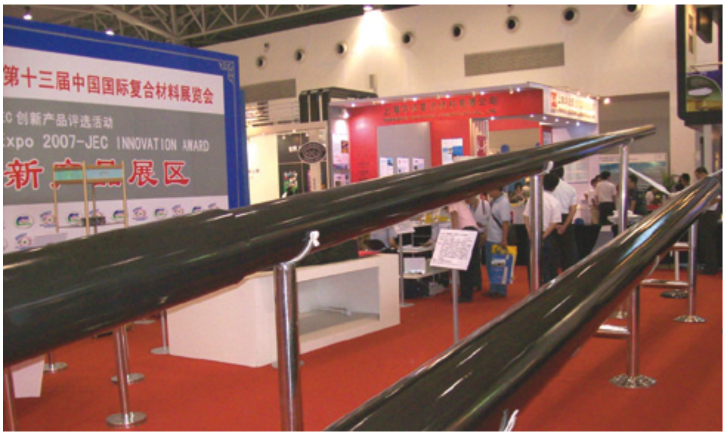


Photo 2.1 Basalt-plastic external light pillars (variable cross-section round profile)

Photo 2.2 Structure of unidirectional fabric based on BCF roving.

Height of profile near the base line h1 can be up to 600, 500, 400 mm, length L 12,20,30 up to 50 meters. It is possible to produce profiles with variable cross-section pic. 2.2.

Advantages of composite force profiles: high strength capacity at a lower weight (8-12 times lower than the alloy high-hardness steel), high resistance to fluctuating loads, fatigue crack and corrosion absence, simplicity of manufacturing, no any restrictions on long structures (except for transportation restrictions).

3. Composite parts of complex form and structure.

Photo 3. Composite products with complex shape

Photo 4. Vacuumed die molds for complex shape composite parts molding.

In motor-car construction, mechanical engineering, and shipbuilding composite structures that are manufactured of materials based on fiberglass are used very often (bumpers, torpedoes, fairings, wings, hulls of boats, boats, yachts). For such structures manufacturing chopped fiber mats are used, roving fabrics and fabrics of folded yarn. Technologies were worked out and gross experience obtained in manufacturing of complex structure parts.

BCF fabric Chopped fiber mat Basalt paper

In Aerospace engineering composite parts of a complex shape are applied: for interior covering panels, radoms and antennas, undercarriage bay fairing, point between fuselage and wing, etc.

Use of prepregs and vacuum die molds provides high mold quality and high composite structures quality themselves.

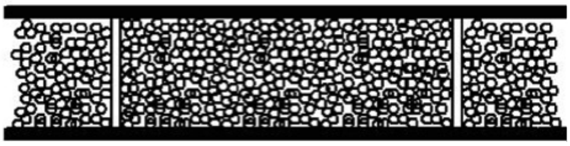
BCF based materials main advantages comparing with fiberglass are: higher strength (1,4 - 1,7 times), low hygroscopicity of basalt fibers (6-8 times) high operating characteristics (resistance and durability under the influence of environment, temperature change, deicing chemicals treatment).

BCF chemical resistance allow to use in bindings chemically active antipyrenes, nonorganic (alkaline) components to reduce composites flammability. Nonorganic bindings application for BCF composites manufacturing makes it possible to produce a new class of nonflammable composites.

4. Flat composite parts with kicker plates - wing ribs, formers (pic. 4)

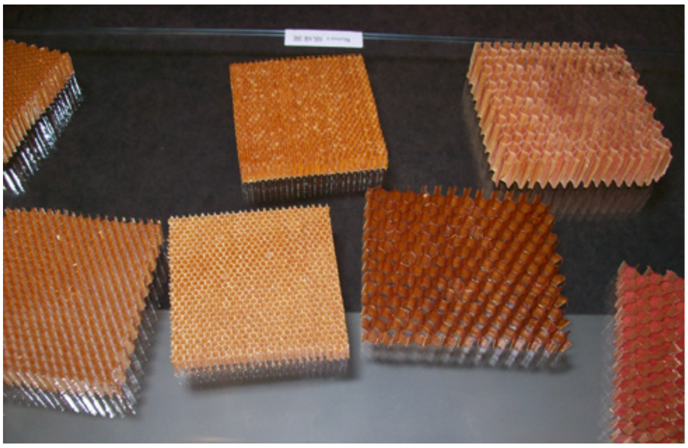
Pic .4 Sample of a flat force element of a wing rib with flanges

5. One and double-layer flat panels.



Double-layer flat panels with fillers

Floor panels and bulkhead web. Panel structure: upper and lower sheet plastic based on fabrics, or nonwoven materials; between upper and lower sheets - honeycomb panels (pic 5-A); force longitudinal elements (pic. 5-Б), volumetric filler based on knitted prepreg (pic. 5-B), foamed filler (pic. 5-Г).



Honeycomb panels

Honeycomb filler are applicate in aircraft. Different materials are used to manufacture them (from metal foil to plastics).

Foamed materials - light filler. Polymeric mass is aerated or polystyrenes are used.

Volumetric fillers based on knitted fabric. Knitted fabric is impregnated with binders (making a prepreg), forming spacious structures which are bond together with panels and polymerized.

6. Structural fuselage coverings.

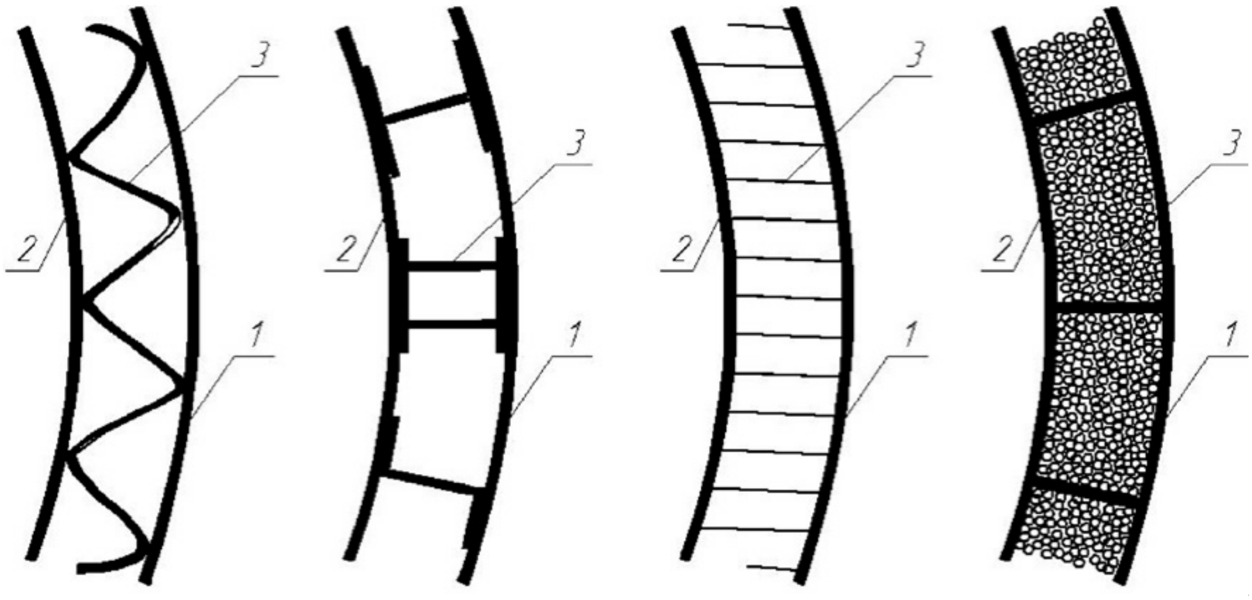
Structural composite coverings are manufactured on the basis of fabrics, chopped fiber mats, basalt paper and longitudinal load-bearing elements located between coverings.

Structural coverings are solid load-bearing constructions. Double-covering structures were worked out at the development of large-diameter pipes technology (F2000, 3000, 4000, 5000, 5400mm). Results of such works are: high cross-breaking strength of pipes, significant (4 times) reduce of large-diameter pipes weight, material consumption reduction and cost reduction.

Composite pipes of a large diameter F 5400mm.

Samples of spacious hollow composite products, blades, high-pressure cylinders.

At pic. 6 composite structures with doubled covering and different kinds of longitudinal elements and fillers are represented.



Pic. 6

Double-covering structure with knurled fitting piece (pic. 6 - A). Between external (1) and internal (2) coverings there is a longitudinal goffer formed of rowing fabrics prepreg. Coverings 1 and 2 are glued with corrugated fabric (3) and build up a strong and hard structure. Double-covering structure with longitudinal profiles (pic. 6 - Б). Between external and internal coverings load-bearing elements (3) (square profiles, I-beams) are embed and glued up with coverings. Double-covering structure with honeycombs (pic. 6 - B). Double-covering structure with foamed filler.

Spacious composite structures with fillers (spacious prepregs, lengthwise beams, foam materials) have a high amount of resistibility with minimum weigh, supply demanded resistibility and toughness of aircraft's body and hull. Advantage of double outer covers is a creation of carrying, tough and reliable structural systems of high diameters and sizes with additional heat and sound isolation functions. Advantages of those structural systems for a frame and the hull of aircraft are obvious.

7. Spacious hollow composite constructive systems.

Spacious hollow composite objects are created based on prepregs, strip lines and unwoven materials.

Production methods: pressure forming (air under pressure is delivered into a prepared form with prepreg), reeling with roving's and strip lines. Spacious hollow constructive systems based on BCF (Basalt Continuous Fibers) are well worked over in production and usage practice.

Technologies and equipment for the production of those items are used in manufacturing of wind generator blades and high-pressure tanks.

Wind generator with blades from 6 to 25 meters endure significant load demand,

their working lifespan continues 25-50 years.
High-pressure tanks from BCF rovings for pressured natural gas (working pressures 240 kg/cm², tanks tested with 500 kg/cm²) offer frequent pressure changings (thousands of tank refilling cycles), are safe for car usage. In aircraft and rocket engineering spacious hollow constructive systems can be used for production of fuel tanks, wing tips, tail fin, stabilizers, ailerons, trailing edge flaps, tankages, spacious constructive systems.

8. Combined composite constructive systems with lengthways force beam profiles and stringers, reinforced with force partitions and double outer cover.
In hull constructive systems there can be used composite BCF carrying beams and lengthways profiles (stringers), reinforced partitions and doubled outer cover. Compound of construction elements is carried out with help of glue compounding, and bolt compounding through embedded parts.
Hull manufacturing with BC is perspective as monolithic composite construction system with a set of reinforced lengthways stringers, without hull partitioning on nose section F1, midsection F2, tail section F3 and their coping with bolt compounding. Same for the wings. This will provide a weight loss of DC aircraft multiplied by 1,2-1,25 times.
Construction questions on the way of wide usage of the BCF constructive systems are solved in general, but there are organization questions – creating of manufacturing facilities for special BCF and composite materials for aircraft and their certification. Technological and manufacturing solutions for composite materials and BCF are well worked over on glass and carbon composites. In BCF branch there are specialized technologies and equipment for BCF production with worldwide priority and large DCF plant building experience. Thus creation of one's own modern DCF productions (plants) based on 4th generation of technological equipment for aircraft engineering is a thing of financing and a desire. China Aerospace Company Co. (CASC) invited Ukrainian specialists in 2003. In the end, there is a successful large BCF production plant "Sichuan Aerospace Tuoxin Basalt Industry Co., LTD" in PRC. Complex testing of BCF composites and their certification in AIAM (ВИАМ) and other certifying centers is needed.

CONCLUSION

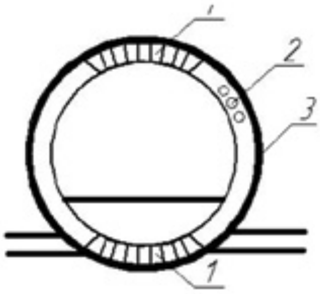
1. Composite materials find more and more wide usage in aircraft engineering. Leading aircraft engineering companies create constructions systems of aircraft where composites are the main material. Composite materials based on roving's, strip lines, unwoven materials tissues and their prepregs can compose a general part of the hull, wings and fins of aircraft.

2. By their resistibility and usage characteristics BCF and DCF composites are the most appropriate supply for aircraft engineering demands, have the best balance of "quality-price" in compare to other available fibers. A task of wide composites usage in aircraft can be successfully solved with help of BCF.

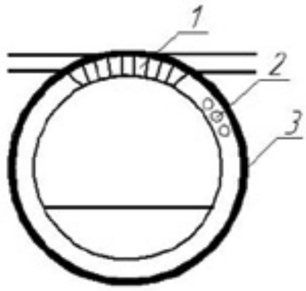
3. The price of BCF composites is 2.5-3 times lower than similar aluminum

alloys constructive systems and 10-12 times lower than carbon composites.

4. BCF materials usage in aircraft engineering will allow lowering the price and weight of aircraft and increasing efficiency of their usage.



The design of the low-wing with the upper and lower longitudinal load-bearing structures (1), transverse frames (2) and double covering (3)



The design of the high-wing with the upper longitudinal load-bearing structures (1), transverse frames (2) and doubles covering (3) of fuselage.

Table 1

Index	BCF	E-glass	S-glass	Carbon fiber	Aramide fiber
Tensile strength, mPa	3000~4840 3400~5380*	3100~3800	4020~4650	3500~6000	2900~3400
Elasticity modulus , hPa	79,3~93,1	72,5~75,5	83~86	230~600	70~140
Elongation to break, %	1,5–2,6	4,7	5,3	1,5~2,0	2,8~3,6
Diameter of the filaments, micron	6~21	6~21	6~21	5~15	6~15
Tex roving (tex), gr / km	60~4200	40~4200	40~4200	200 - 2400	100–1800
Application temperature, ^{o}C	-260~+800	-50~+380	-50 +300	-50~+700	-50~+290

Prime cost of industrial manufacturing, $ / kg	1,1–1,8	1,4–2,0	3,0–3,2	25–30	17–22
Sales price, $ / kg	2,5–3,0	1,5–2,5	4,0–4,5	35–60	35

Table 2

Diameter of the filaments, micron	5.0	6.0	8.0	9.0	11.0
Specific tensile strength of filaments, kg / mm2.	215	210	208	214	205

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