APPLICATION OF HIGH-STRENGTH POLYMER COMPOSITES IN MIL HELICOPTER DESIGNS

by

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One of the central problems in current helicopter engineering is development and improvement of nonmetallic materials. Metals have been replaced by high-strength polymer composites that ensure weight saving, higher service life, more reliable operation and combat survivability of helicopters.

Starting from the mid-60s, high-strength polymer composites found wider application in helicopter designs. In 1969 the weight of the Mi-24 components made of these materials (there only fiberglass was used) was 2% of the weight empty. In 1977 the weight of the Mi-26 components made of high-strength polymer composites increased to 5% of the weight empty. Here glass- and carbon fiber plastics were used. Their application in manufacturing vital components, such as main and tail rotor blades, horizontal stabilizer skins, service tank panels and cover, lower part of the vertical stabilizer trailing edge, radar radome, edge formers and door cover in the fuselage nose section, has resulted not only in a reduction in the weight empty, but in improvement of service and calendar lives of this aircraft as well.

In the Mi-28 helicopter born in 1982, the weight of components made of high-strength polymer composites increased to 19% of the weight empty. The Mi-28 is a combat helicopter where provision of combat survivability alongside with increased fatigue strength has had an impact on such structural components as the fuselage nose section, fuel tanks, all kinds of walls including firewalls, and, certainly, the main and tail rotor blades. An outstanding contribution to application of high-strength polymer composites in the Mi-28 was made by our General Designer, Doctor of Science M.V. Vineberg. Under his direct supervision, sandwich panels made of these materials, ceramic armour plates, etc. were developed and incorporated into the helicopter design. The comprehensive ballistic tests that these components succesfully passed is another confirmation of their extremely good behaviour under extreme operational conditions.

A number of new materials were used in this helicopter, as well as new manufacturing methods were deleloped for their production. The cockpit canopy and doors, the horizontal stabilizer skins are manufactured of fiberglass by using the layup method. The door covers and frames around door openings, the leading and trailing edges, as well as the tip fairing panels of the vertical stabilizer, firewall panels, the tail rotor drive shaft covers, slip rings and sight casing are made of aramid fibers by using the same manufacturing method, i.e layup. Starting from this aircraft, aramid fibers are finding still wider application due to their physical and mechanical properties.

In the mid-80s our production facility got an opportunity to master a new method used for manufacturing components by "dry" fiberglass and aramid fiber winding on NC machines. This method is used to manufacture fiberglass main and tail rotor blade spars, vertical stabilizer spar, flexible hoses for the ventilation and heating systems for the Mi-28.

For the Mi-8TG helicopter, a version capable of operating on gas fuel, fuel tanks are made of aramid fibers.

The development of the new Mi-38 helicopter (it began in 1992) is based on the experience gained during design and manufacture of parts and components made of high-strength polymer composites. The upper part of the cockpit, frames around door openings, cargo door panel and some parts of the vertical stabilizer are made of fiberglass by using the layup method. The side panels are of sandwich structure with Nomex honeycomb used as the sandwich core and internal skin made of aramid fiber sheets, while the bottom sandwich panel skin is made of fiberglass. The tail boom is an all-aramid fiber structure manufactured by the winding method, and the fiberglass spar of the vertical stabilizer is made in the same way. The rear fairing of the tail boom, cargo door, and vertical stabilizer skins are made of aramid fibers.

If we add the material used in the main and tail rotor blades to the components made of high-strength polymer composites, the total amount of high-strength polymer composites will increase to 29% of the weight empty of the Mi-38.

Thus, wider application of high-strength polymer composites has allowed us not only to reduce the weight empty of the helicopters and to increase their payload capacity, but to extend the service lives of these aircraft under any climatic conditions, as well as to improve their crashworthiness.

The advantages of high-strength polymer composites are most conspicuous when they are used in helicopter main and tail rotor heads and blades.

At present, in the main and tail rotor heads, elastomeric bearings and other metal and elastomeric parts, fabric-woven bearings for rotor head hinges, bonded sacrificial parts, torsion packs incorporating antifriction polymer materials are used. They have been tested in the Mi-28 helicopter and have been well proven in actual service.

Chief Designer, Doctor of Science M.A. Leikand has made a major contribution to new head designs. Heads made of unidirectional high-strength polymer composites having different moduli are being designed under his supervision; they can withstand high fatigue loads, carry bending, compressive, torsional and tensile stresses, they are insensitive to environmental conditions. They have allowed us to design a radically new rotor head construction of long service life and high reliability for medium and light helicopters.

The complexity of designing main and tail rotor blades is defined by a variety of functions they perform. In the helicopter they perform functions of lifting and control surfaces, as well as provide propulsion. At the same time the design should be absolutely fail-safe, lightweight, capable of withstanding significant vibratory stresses.

High-strength polymer composites have high specific strength, corrosion resistance, they can operate under alternate loads for a long time; all these properties make them the most promising material to be used for blade design. Even such a serious inherent disadvantage of composites as a low modulus of elasticity which is considered unacceptable for a majority of constructions can be of advantage for blades in a number of cases, because the blade elastic line under the conditions of forced oscillations is mainly determined by high external loads acting in different directions, and the internal structural stiffness affects it only slightly as it defines the nature of resonance phenomena and different kinds of self-oscillations. Therefore when the composite material modulus of elasticity is lowered within certain limits and the strength remains the same, as a result, the structural fatigue strength margin increases.

However, the main advantage of any composite material when it is used in the blades is its failure mode in case of any processing or service-induced defects.

Our vast experience accumulated during many years of blade operation has shown that all accidents that occur due to blade failures can be mainly attributed to some processing or service-induced defects.

Fatigue failures of the blade metal spars, in case these defects are revealed, develop very fast, like an avalanche. Using anisotropic properties of composite materials, a blade construction can be designed that can have the so called "soft", progressive failure characteristics. In this case a gradual change in the blade stiffness is observed, additional vibrations occur and the blade itself is continuously indicating some defect for quite a long time.

Composite blade specimens sustaining combat damage have been tested; the test resuts obtained have substantiated their high survivability under these conditions.

The blade design team headed by B.S. Sirotinsky has chosen the D-shaped spar forming the leading edge section of the blade. The tail rotor blade spars for the Mi-26, Mi-28 and Mi-38, as well as the main rotor blade spars for the Mi-28, Mi-34 and Mi-38 are manufactured automatically by using the method of spiral winding of unidirectional prepreg tapes on special-purpose winding machines.

Tape winding can be made at different angles about the centerline of the spar, from 10-15 degrees minimum required to take up axial loads, and up to 45 degrees required to ensure high torsional stiffness. Preimpregnated material used as a filler has high-modulus glass filaments; in layers oriented at 45 degrees, the filler can be combined with carbonfiber strands.

Having been wound around the mandrel, the spar is placed into the closed heated mold where it is cured under the required internal pressure applied to its inner surface.

The blade trailing edge section consists of thin, lightweight aramid fiber skins and Nomex honeycomb.

The blades are fitted with an electro-thermal anti-icing system whose heating elements comprising insulation layers and current-conducting cloth are made of polymer composites.

Comprehensive tests conducted and the experience gained in the process of

Table 1

Mechanical Properties of Epoxy Unidirectional Glass- and Aramid Reinforced Plastics Containing 60-63% of Filler (by Weight)

Ref. No.	Properties	Aramid-reinforced plastic	Glass-reinforced plastic
1.	Density, gf/cu.cm	1.32	2.10
2.	Ultimate tensile strength, MPa		
	along fibers	18.10	17.60
	across fibers	0.11	0.27
3.	Ultimate compression strength, MPa		
	along fibers	3.00	6.20
	across fibers	0.76	0.80
4.	Ultimate bending strength, MPa	6.60	9.70
5.	Ultimate shear strength, MPa	0.33	0.48
6.	Young's modulus, MPa		
	along fibers	900.00	680.00
	across fibers	31.40	104.00

Table 2

Comparative Physical and Mechanical Properties of Epoxy Plastics Containing 62-65% of Filler (by Weight)

Plastic type	Density, gf/cu.cm	Tensile strength, MPa	Specific strength, km	Young's modulus MPa	Specific modulus, km
Glassfibers	2.08	17.5	84.1	600	2.9
Aramid fibers	1.32	18.0	136.4	900	6.8
Carbon fibers	1.4-1.5	10.0	69	1500	10.3

Table 3

Mechanical Properties of Epoxy Textolites Based on Aramid-,Glass- and Carbon Reinforced Cloths Containing 55-60% of Filler (by Weight)

Ref. No.	Properties	Textolites		
		Aramid fibers	Glass fibers	Carbon fibers
1.	Density gf/cu. cm	1.3	1.7	1.45
2.	Ultimate tensile strength, MPa			
	warpwise	6.8	4.9	7.00
	weftwise	6.9	3.1	-
3.	Ultimate compression strength, MPa	2.1	-	6.50
4.	Ultimate bending strength, MPa	5.2	-	10.20
5.	Young's modulus, MPa			
	warpwise	305.0	247.0	1200.00
	weftwise	320.0	220.0	-

blade operation in actual service have shown that, in comparison to metal blades, polymer composite blades have higher aerodynamic efficiency stemming from the possibility of using an optimal aerodynamic configuration and blade contour repeatability provided by molds; they are lighter by weight, have high reliability and an actually unlimited service life, high combat survivability.

The physical and mechanical properties of the high-strength polymer composites are determined by the filler type. We started to experiment with fiberglass material. Our transition to aramid fibers has been dictated by new design developments. The comparison of epoxy unidirectional plastics based on different types of fillers (Tables 1 and 2) has revealed their advantages and disadvantages [1].

The manufacturing process used to fabricate epoxy unidirectional plastics is the so-called winding method. Fiberglass blade spars and aramid fiber tail booms are fabricated in this way. Application of hybrid fillers (i.e. fillers that are a combination of glass and carbon fibers) in the Mi-38 main rotor blade spar has ensured the required blade stiffness limit.

Aramid fiber textolites have been widely used in all the Mi-28 and Mi-38 components. The textolite behaviour differs greatly from that of epoxy unidirectional plastics. Application of polymeric melts as binders (Table 3) has resulted in obtaining textolites possessing a high level of strength properties [2]. At the same time air permeability of textolite sheet skins has been greatly reduced, while environmental conditions of manufacturing plastics from preimpregnated materials have been improved [3].

If all the gains obtained due to application of high-strength polymer composites in Mil helicopters are summed up, then it should be noted that the utilization factor of materials has increased by 0.8-0.9%, man-hour and power requirements have been reduced by 1.5-3.0 times in manufacturing sophisticated components, the weight of airframe components has been reduced by 14% while the service lives of these components have become 3-4 times longer, and their calendar lives have increased up to 10 years.

Everything said above is of great importance, interest and use for the state-of-the-art aviation technology, However, application of high-strength polymer materials can become wider only if lightweight materials having high Young's modulus, high resistance to torsional stresses and high fatigue strength are developed; but this problem should be solved not by improving elasticity of the polymeric matrix which will inevitably lead to increased yield of the composite material, but by developing new kinds of fillers.

So, new materials possessing new properties, new design developments in the field of our helicopter industry may enable us to design a twenty first century helicopter, lightweight, maneuverable, cost-effective, reliable in operation with unlimited service and calendar lives.

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