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Theoretical and experimental investigations of composite helicopter units.

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Abstract

Issues of introducing composite materials in light-weight helicopter structures are considered. Theoretical and experimental studies were conducted, which enabled stablishing non-traditional usage fields for composite materials. For example, the theoretical studies estimated the weight efficiency of composite materials in helicopter structures, and the experiments under a new principle made it possible to attain a high energy-absorption level in a composite-based skid landing gear.

Polymer composite materials based on thermoset and thermoplastic matrices with carbon, organic and glass fibers are known to ensure high specific values of strength, stiffness, and crack initiation/propagation resistance in case of alternating loads. Therefore, these materials are relied upon in upgrading static and fatigue strengths of aircraft structures where, in addition, the gross take-off weight should be reduced. However, the composites, unlike metals, feature the following disadvantageous properties:

- brittle fracture, thus the sensibility to stress concentrators and mechanical impacts;
- dependence of mechanical characteristics on environmental conditions;
- rather wide variability of properties.

These circumstances reduce the strength of composite structures, make designers apply large safety factors, and may degrade the expected positive effects of using composite materials in helicopter structures.

In this connection the concept of utilizing the materials in structures of light-weight helicopters (Fig. 1) that is based on the past experience and preliminary efforts on their application. Introduction of composite materials is known to have been begun in main rotor blades; here, high efficiency may be attained in realizing fatigue resistance of composites including hybrid materials based on Glass Fiber Reinforced Plastics (GFRP) and Carbon Fiber Reinforced Plastics (CFRP). The present combination can also be used in control rotor blades. In this case the structures of blades for main and control rotors can rely upon tubular spars which are rather easy to manufacture by winding. It should be noted that the currently available experience of utilizing composite materials in main rotor blades will also be employed in the future.

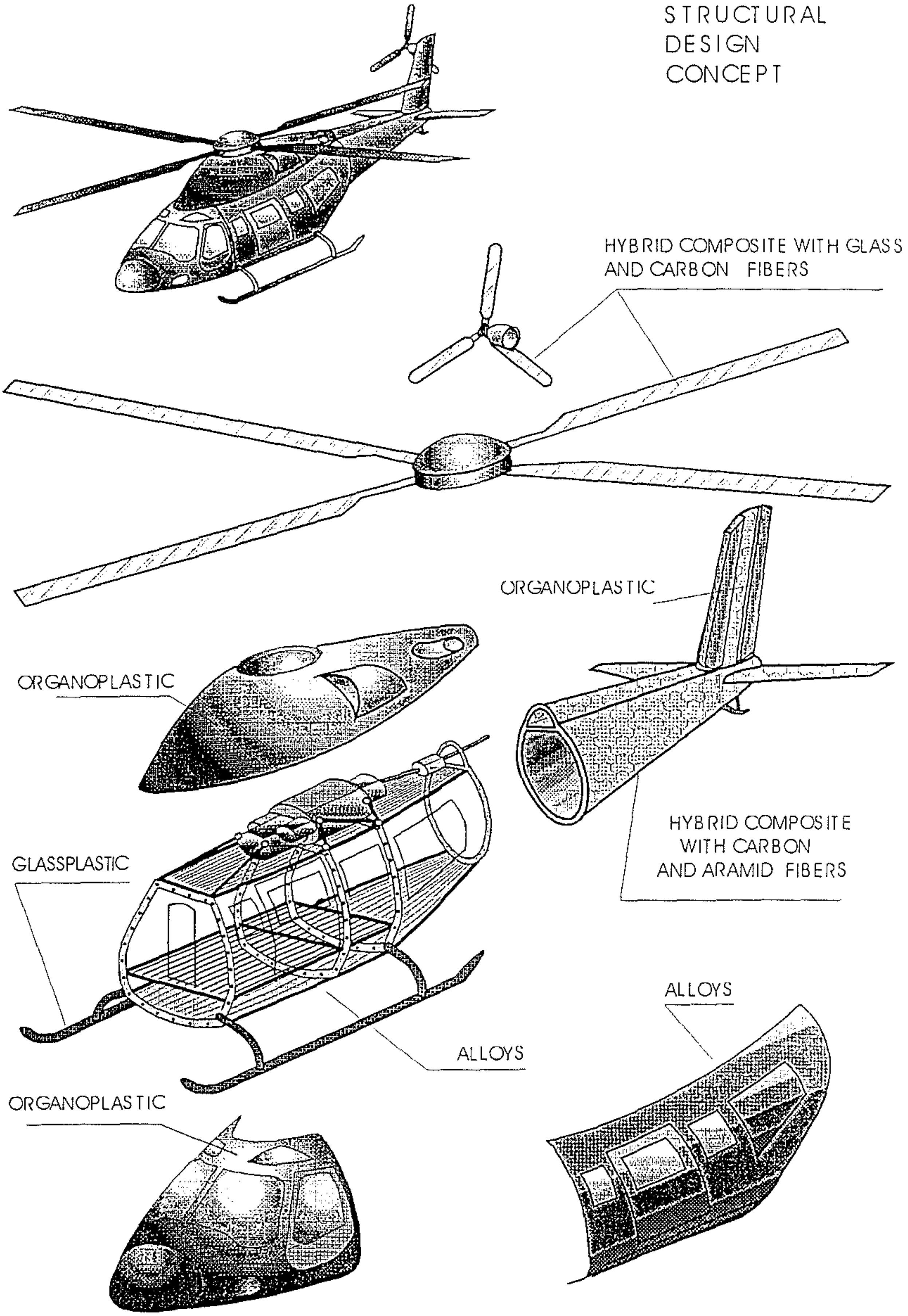
STRUCTURAL DESIGN CONCEPT
HYBRID COMPOSITE WITH GLASS AND CARBON FIBERS
ORGANOPLASTIC
ORGANOPLASTIC
HYBRID COMPOSITE WITH CARBON AND ARAMID FIBERS
GLASSPLASTIC
ALLOYS
ALLOYS
ORGANOPLASTIC

Fig. 1

Using composite materials in helicopter rotor hub elements is a more challenging issue. In this case the strength design conditions include the cruise flight and the breaking of gliding - these are the main conditions for establishing fatigue and static strength, respectively. Variable in-flight stresses in hub components are the result of applying the bending moments and shear forces (in vertical and horizontal planes) and blade torque. These features of loads necessitate specimen-based evaluation of stresses and strength of composite hubs; the investigation revealed that an element transferring the forces from a blade to the hub could make the maximum use of the needle-type connection concept. For this purpose the hub structure should incorporate a metal ring flange which interacts with the hub through the needle joint. Experience shows that the needle joint makes it possible to notably improve the composites efficiency.

As for the primary helicopter structure, composite materials are especially suitable in tail booms. The latter may include both CFRPs and organoplastics which improve impact resistance of the material. It should be noticed that the tail boom efficiency criteria include not only strength at a minimum structural weight but also the structural damage tolerance. The major area of efforts in ensuring high damage tolerance of composite structures is the use of statically indeterminate structures - that is, of several paths for load transfer. One of ways to prepare a highly tolerant tail boom is to manufacture a multiple-spar beam whose skin has 45-degree layers. The other method is to use an isogrid structure with a skin. Experimental results available show the structure to have high efficiency upon mechanical damage.

Greatly promising is also the use of composite materials in structures of skid landing gears for light-weight helicopters. In this case the structural ability to absorb much energy of ground impact enables composite materials to ensure certain weight improvement. Here, oscillations are absorbed due to both the well-designed arrangement of the landing gear and the damping capability of composite materials. Below, these issues are addressed in more detail.

Thus, the concept proposed defines major areas of working on the composites utilization in light-weight helicopter structures; currently, the concept is actively employed in scientific and design organizations.

Within the present concept a large amount of theoretical and experimental studies were carried out; their accomplishments have considerable scientific and practical importance.

Of interest are results of theoretical estimation of composites efficiency in light-weight helicopter primary structures. These were based on analysis of loads and structural concept by the package of computer programs for weights analysis.

Loads were simply computed to show that the body components are stressed to low levels. This circumstance has been taken into account when establishing the level of weight coefficients which were determined by employing statistical relations derived from analytical and experimental studies, allowing for all design criteria in real use:

- ensuring static strength under ultimate loads;
- ensuring damage tolerance (i.e., ensuring the required strength of the structure damaged in service, when the limit load is applied);
- ensuring fatigue strength under variable loads, taking into account environmental attack;
- ensuring the required structural stiffness; and
- obeying the size constraints with consideration of specific designer solutions.

These aspects and the available data about really manufactured composite structures were taken into account when establishing the view of weight effects of the composite materials amounts utilized (Fig. 2).

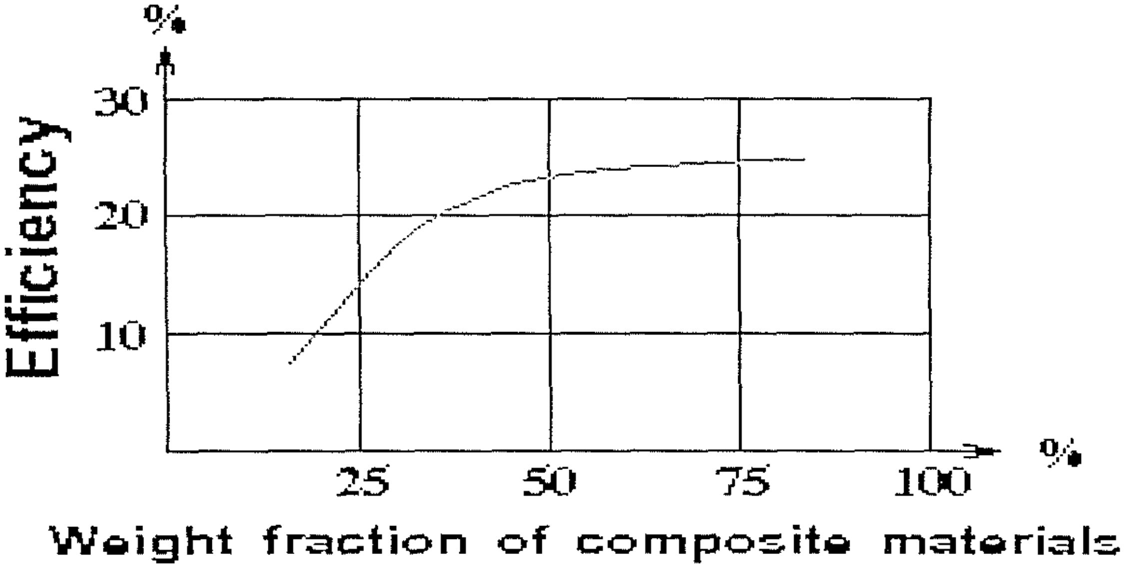

Fig. 2

One can see that, despite the low stresses in the light-weight helicopter primary structure, the weight of the all-composites structure may ensure the helicopter weight reduction by 25%. It should also be noted that increasing the composites weight fraction above 50% does only insignificantly improve efficiency. Taking into account the high cost of composite materials, the above factor suggests utilizing some combinations of materials.

At later stages the composite materials efficiency may be improved by refining the stress field evaluation through, firstly, the use of more detailed finite-element models, secondly, implementation of non-traditional designer solutions, and, thirdly, refinement of strength criteria.

The possibility to involve composite materials in light-weight helicopter landing gear structures is confirmed by conventional development tendencies and related to conditions of meeting the FAR-29 requirements.

During the experimental stage of the effort we statically tested the skid landing gear in order to determine stresses and strains and ultimate loads; also, we carried out dynamic tests to establish the structural damping characteristics.

Also, efficiency of the materials used should be validated; requirements for structural materials and structural concepts in what concerns damping should be detailed; to do so, we developed a method for dynamically testing the landing gears. The method is based on the reversibility principle: the oscillatory process caused by skid impact at touch-down is assumed to be identical to the situation of the preloaded landing gear being unloaded instantly. In this case we intensified skid oscillations by rigidly installing some concentrated weights. Clearly, the present approach does not involve the friction influence on the damping capability - unlike the drop tests; this is an obvious advantage of the method proposed. The general view of the system and the geometry of loading the elements of a skid landing gear during static strength tests may be seen in Fig. 3.

In the experiments we recorded both skid deflection at certain points and strain gage signals; additional data processing enabled us to determine the helicopter landing gear energy-absorption capability.

In order to assess efficiency of damping of the composite materials used in the skid landing gear we conducted dynamic tests which simulated a helicopter landing. A load pulse applied to the landing gear implied an oscillatory process with damping; it was recorded by test equipment. The study of the landing gear damping influence on oscillation amplitude is a very important thing: the damping intensity affects stresses in the elastic system.

Damping in real structures is known to depend on a number of factors: internal friction in the material, structural features (such as supports and joints), and environment. It is natural that in the test data obtained it is difficult to separate the immediate influence of the internal friction on the damping, to outline the damping caused by supports and/or environment. In this connection we assumed that the major damping factor in the skid landing gear is the internal friction in the material; it is the very factor which is given considerable attention currently. It has been established that the internal friction is mainly defined by plastic deformation, atomic intracrystal diffusion, thermoelastic effects, and magnetoelastic hysteresis in ferromagnetic materials.

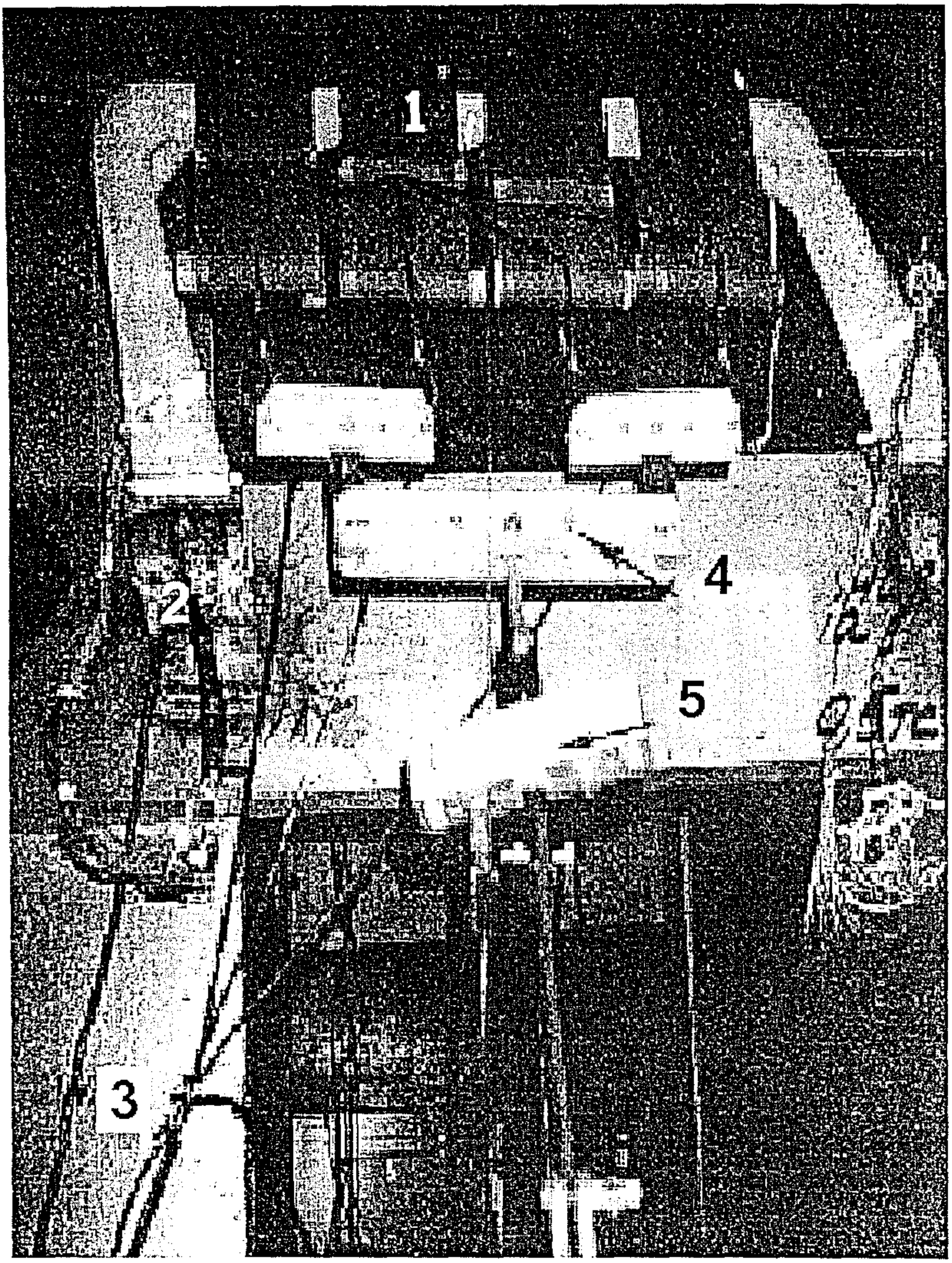

Fig. 3.

1 - Load-distribution strips; 2 - Landing gear attachment device; 3 -Load-carrying columns; 4 - Lever-based load application system; 5 - Load cell.

Experimental research of damping in various materials reveals that energy dissipation in oscillations for a certain frequency range does not depend on oscillation frequency, but does depend on deformation amplitude and temperature.

There exist two usual methods for determining the materials damping; the first method is based on immediate measurement of amplitudes of oscillations in a specimen; the second one measures the energy dissipation rate during forced oscillations at a resonance frequency. With an oscillogram of the freely damped vibrations in hand, we can determine the decrement by measuring the amplitudes. Upon processing the oscillograms we get the ratio of amplitudes at three points taken at equal distances along the skid (point 1 is at the fore strut and point 3 is at the aft strut); also, we get the mean value; these are reported in Table 1. It also provides decrements. These characteristics are shown for two load values (250 kg and 50 kg) when the skid carried a 40-kg weight.

Table 1.

Load	Parametres	Drop	Amplitude ratio				Decrement
			1	2	3	Average	
F=250 kg	Strain	1	33/24	27/17	17/11,1	1,48	0,392
		2	33/20	20/13	13/9,1		
	Displacement	1	28/18	18/12,1	12/7,5	1,53	0,428
		2	21/15	15/9,9	10/6,1		
F=50 kg	Strain	1	14/8,9	9/6,1	------	1,55	0,438
		2	13/7,9	------	------		
	Displacement	1	12/6,9	7/4,1	------	1,54	0,431
		2	13/9,1	9/6,9	------		

It should be noted that, regardless of the load value, the patterns of deformation/displacement amplitude profiles are much identical. For example, the amplitude at the aft strut is much less; this is due to landing gear structural features: the aft part of the skid is closer to the supporting structure.

The other important result of these tests is that the mean values of deformation and displacement are much identical. Decrement is only slightly depending on loads; however, its value is very important. For example, upon comparing the decrements with those for steels (Fig. 4) one can see that the decrement in composite materials is greater by an order of magnitude than that in chromium-alloyed steel. However, these data must be regarded as preliminary information since it was difficult to outline the fractions associated with the internal friction.

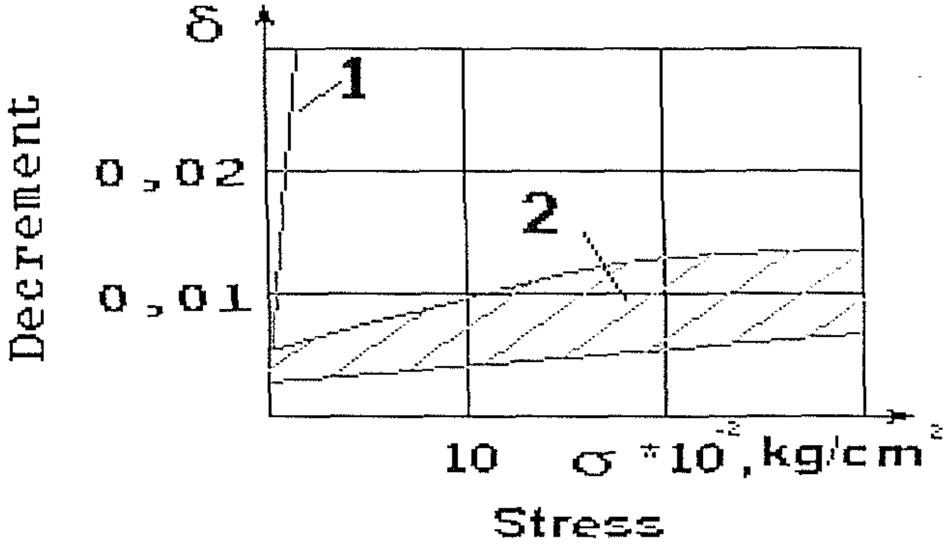

Fig. 4.
1 - Composite; 2 - Chromium-alloyed steel

With this, the analysis of studying the landing gear dynamic behavior makes it possible to evaluate structural damping to be assigned to structural features and the materials damping.

The load-bearing capacity of the skid landing gear was determined through static strength tests. For example, when loading the structure to $1.96P^p$ both the load and strain were increasing smoothly. No changes or permanent strains were revealed in the structure. When loading the structure from 195% to 211% of P^p the load was periodically decreasing by 2% to 3% because the material in the aftstrut was being delaminated along the axis from the base to the skid; during the further loading we observed active delamination and fracture of external layers. The landing gear load-bearing capacity turned out to be $2.52P^p$. This means that the margin of strength exceeds the design value, and there are possibilities to improve geometry of the skid landing gear and increase its weight efficiency.

It is seen that the present method allows researchers to perform comprehensive studies for improving and estimating the use of composite materials in the skid landing gear structure.

So the theoretical and experimental studies accomplished make it possible to extend the composite materials usage range in light-weight helicopter structural units.