

STUDY OF DYNAMIC CHARACTERISTICS OF HYBRID TITANIUM-POLYMER COMPOSITE MATERIALS

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Abstract: Low specific weight and high mechanical strength (especially at elevated temperatures) of titanium and its alloys make them very valuable aviation materials. In the field of aircraft construction and aircraft engine production, titanium is increasingly replacing aluminum and stainless steel. At present, aircraft developers are restructuring the whole material science concept of aircraft construction, actively involving and using various types of composite materials based on titanium alloys. Combined with the properties of titanium, FML composites based on titanium have greater stiffness, impact resistance, heat resistance, and corrosion resistance especially compared to similar aluminum-based materials. The paper investigates the dynamic characteristics of hybrid titanium-polymer composite materials (TPCM) based on titanium alloy BT-23 and fiberglass with a brief presentation of the main characteristics of prepregs. The process of manufacturing specimens for testing including heat treatment, ply laying scheme and reinforcement scheme in two variants is described. The results of experimental studies of natural frequencies and damping coefficient by the method of free damped oscillations in free oscillations of TPCM plates are presented. The tests are carried out on a specially designed unit with a triangulation sensor in the variant of vertical loading. Two identical specimens with different overall dimensions are tested. Each specimen was tested with a different amplitude. Five tests were conducted for each amplitude. The physical constants of the specimens were pre-determined in static tests. The natural frequencies and damping coefficients for the titanium-polymer composite specimens were found.

Keywords: titanium-polymer composites, natural frequencies; vibrations; TPCM; damping coefficient; layered composites

ИССЛЕДОВАНИЕ ДИНАМИЧЕСКИХ СВОЙСТВ ГИБРИДНОГО ТИТАН-ПОЛИМЕРНОГО КОМПОЗИЦИОННОГО МАТЕРИАЛА

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Аннотация: Малый удельный вес и высокая механическая прочность (особенно при повышенных температурах) титана и его сплавов делают их весьма ценными авиационными материалами. В области самолетостроения и производства авиационных двигателей титан все больше вытесняет алюминий и нержавеющей сталь. В настоящее время разработчики авиатехники перестраивают всю материаловедческую концепцию строительства самолетов, активно привлекая и используя различные виды композиционных материалов на основе титановых сплавов. В сочетании со свойствами титана композиционные материалы FML на его основе обладают большей жесткостью, ударостойкостью, термостойкостью, коррозионной стойкостью особенно по сравнению с аналогичными материалами на основе алюминия. В работе исследуются динамические характеристики гибридных титан-полимерных композиционных материалов (ТПКМ) на основе титанового сплава BT-23 и стеклопластика с кратким приведением основных характеристик препрегов. Описан процесс изготовления образцов, для испытаний включая термообработку, схема укладки слоёв и схема армирования в двух вариантах. Представлены результаты экспериментальных исследований собственных частот и коэффициента демпфирования по методу свободных затухающих колебаний при свободных колебаниях пластин ТПКМ. Испытания проводятся на специально сконструированной установке с триангуляционным датчиком в варианте вертикального нагружения. Испытываются два однотипных образца с разными габаритными размерами. Каждый образец испытывался с различной амплитудой. Для каждой амплитуды проводилось по 5 испытаний. Физические константы образцов предварительно определены в

статических испытаниях. Найдены собственные частоты и коэффициенты демпфирования для образцов титан-полимерного композиционного материала.

Ключевые слова: сферическая композитная оболочка; контактная задача; теория многокомпонентного анизотропного сухого трения

INTRODUCTION

The study of dynamic characteristics is one of the main points for compiling a complete picture of the properties of materials in various branches of engineering, especially hybrid titanium-polymer composites or metal-fiber laminate (FML). A number of articles [1-6] investigated a wide range of issues devoted to various stages of creation, study of properties and characteristics, metal-polymer materials based on titanium [6]. These materials have high corrosion resistance and strength in combination with low density, as well as paramagnetic properties and are widely used in aviation, space technology, shipbuilding. Special attention has been paid to the research and development of metal polymers based on thin sheets of titanium alloys VT20 and VT23M [1-6]. Compared to similar materials based on aluminum, TPKM has advantages in thermal conductivity, since the thermal conductivity of titanium is 13 times less than that of aluminum [1]. Traditional titanium alloys have high mechanical characteristics, but all possibilities are currently exhausted to increase their strength and reduce density, especially in comparison with foreign analogs, β -alloys, which have a complex alloying system and contain scarce and expensive elements (e.g., alloys SP-700, Beta CEZ). This is another advantage of TPKM.

The layup configuration can be different depending on the working conditions and the task to be performed. Composite materials based on titanium are widely used in helicopter main rotor blade spar, in Mi 26 tail rotor blade spar, in Mi-26 stabilizer spar, in Mi-2 tail rotor blade, which have special requirements related to rigidity, strength, thermal insulation. One of the main tasks was to determine the dynamic characteristics of such material: natural frequencies, bending stiffness and damping

coefficients, to build a mathematical model based on the plate for prediction in the design of structural elements of aircraft operating under conditions of high-frequency vibration loading. This paper investigates the dynamic characteristics of titanium-polymer composite material based on titanium alloy BT-23 by the method of free damped oscillations [7-8].

MATERIALS AND METHODS

A promising material among metal composite laminates is a laminate based on titanium and glass or carbon fibers. The use of titanium increases the stiffness of the composite compared to the metal composite material based on aluminum alloys and has high corrosion resistance, including in aggressive environments [9-10]. The use of different thickness and different number of metal and composite layers or different arrangement of fibers allows to change the properties of such material, as well as other types of metal composite laminate [11-12]. For high flight speeds, titanium FML(TPCMs) have high heat resistance and can withstand working surface temperatures where they are used up to 300°C. TPCMs are mainly used in regions where high temperatures and high fracture toughness are required. In addition to these advantages, TPKMs have high fracture toughness, high impact resistance and low density.

This paper investigates samples from hybrid titanium-polymer composite material (TPCM) based on titanium alloy BT-23, which are metal plates produced by vacuum-autoclave method after assembly of layered billet packages. Table 1 gives the characteristics of the materials used in the test. Figure 1 shows the samples of titanium-polymer composite material. Two types of TPCM specimens with dimensions

280mm x 20mm x 0.8mm and 180mm x 10mm x 0.8mm cut from one plate by guillotine were investigated.



Figure 1. The types of TPCM samples under study are from the top a sample measuring 280mm x 20mm x 0.8mm and from the bottom a sample measuring 180mm x 10mm x 0.8mm

Table 1. Material Characteristics

Material	ρ , kg/m ³	E, GPa	Tensile strength, MPa
BT-23	4570	100-110	980
BIIC-37K10	1700-1800	42/11,5	1500/75
BCK-14-2M	1780	3,7	92

To form the samples, a monolithic panel with dimensions of 500 x 250 mm was manufactured. Three layers of titanium foil of high-strength deformable titanium alloy VT-23 0.08 mm thick, between which alternate layers of fiberglass plastic based on prepreg KMKS-2m.120.T60. Fig. 2 shows the laying scheme of TPKM layers. Table 2 shows the scheme of laying and reinforcement of the material.

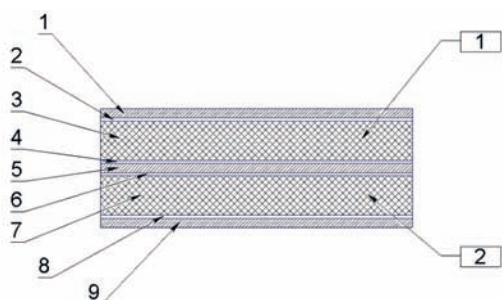


Figure 2. Layout scheme of TPKM layers. On the left 1,5,9-VT23, foil; 2,4,6,8-layer VK-25; 3,6-KMKS-2m.120.T60. On the right laying package 1 and 2

Table 2. Layout and reinforcement scheme

№	Layer	Layout of conditions 1, deg	Layout of conditions 2, deg
	1	VT -23, foil	VT-23, foil
1	2	0	0
	3 (KMKS-2m.120.T60)	0	90
	4	0	0
	5	VT-23, foil	VT -23, foil
2	6	0	0
	7 (KMKS-2m.120.T60)	0	90
	8	0	0
	9	VT-23, foil	VT -23, foil

Layers 1 and 9 of titanium alloy foil BT-23 are covered on one side, and layer 5 - on both sides, with an elastic sub-layer based on phenol rubber composition VK-25. This provides creation of conditions for improvement of adhesive interaction and work of interphase boundary metal foil - polymer composite. Layers 2 - 4, 6 - 8 are fiberglass plastic VPS-37K10 on the basis of prepreg KMKS-2m.120.T60. The reinforcing filler in this fiberglass laminate is glass fabric T-60(VMP)-14 based on high-modulus high-strength fibers. The binder is epoxy composition VSK-14-2m.

Laying of blanks was carried out manually. Further for realization of vacuum-autoclave molding a vacuum bag was made with application of typical auxiliary materials (anti-adhesion separating films, drainage layers, vacuum film and sealing tourniquet). The molding of the blank was carried out according to the typical curing regime. Curing for 3 hours at a temperature of 150 °C and molding pressure of 5 atm.

RESULTS

During the tests, the specimen is fixed parallel to the plane of the table for vertical loading. The rod in the form of a metal bar is removed from the specimen as sharply as possible, in order to obtain a clean interference-free plot of

amplitude versus time for further processing. The maximum amplitude is limited by the possible delamination of the specimen during testing and did not exceed 20 mm. The setup itself ensures the absence of external interference and transients. The setup with a fixed TPCM specimen is shown in Fig. 3.

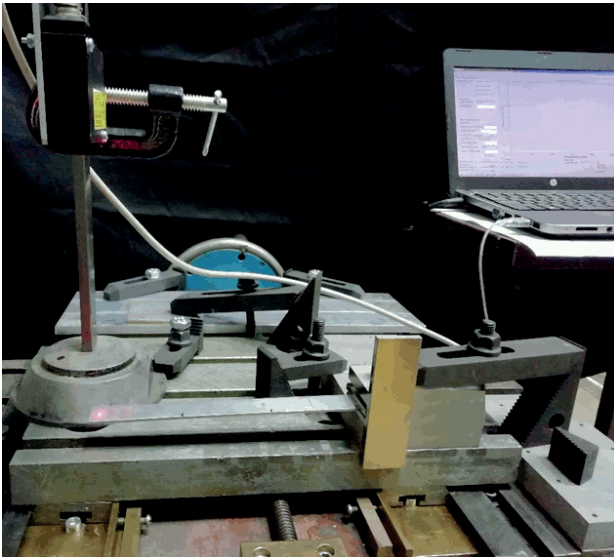


Figure 3. Specimen in the vertical loading setup

A RIFTEK RF603 triangulation laser sensor was used to fix the amplitude. The tests were carried out on the specimen out of the clamping tooling 250mm and 150mm. The loading was performed vertically. The test results were processed using the fast Fourier transform method to obtain the amplitude-frequency response (AFR) of the realized oscillations [4]. The peak corresponding to the first resonant frequency was determined on the obtained AFC. The width of the found peak allows determining the logarithmic decrement of the sample based on the ratio (GOST 30630.1.8-2002, ASTM E756) [7-8]:

$$\zeta = \frac{\omega_2 - \omega_1}{2\omega_0}$$

where ω_0 – is the resonance frequency, and $\omega_1 < \omega_2$ – are the frequencies near resonance at which the amplitude value decreases by a factor

of $\sqrt{2}$ compared to the resonance amplitude. From the data obtained, the natural frequency of each sample was determined and the damping coefficient was determined, and the results are summarized in Tables 3.

Table 3. Natural frequencies and damping coefficients of 150mm and 250mm TPCM samples

sample (reach length)	sample	Natural frequency, Hz	Damping factor	Average natural frequency, Hz	Average damping factor	
250 mm	1	1	29,166	0,039	29,109	0,040
		2	29,095	0,042		
		3	29,073	0,039		
		4	29,068	0,040		
		5	29,142	0,041		
	2	1	27,755	0,036	27,887	0,037
		2	27,818	0,039		
		3	27,917	0,038		
		4	27,973	0,039		
		5	27,971	0,035		
	3	1	28,853	0,036	28,840	0,036
		2	28,837	0,037		
		3	28,831	0,037		
		4	28,832	0,035		
		5	28,847	0,036		
150 mm	1	1	38,661	0,017	38,625	0,018
		2	38,659	0,018		
		3	38,605	0,019		
		4	38,605	0,017		
		5	38,593	0,019		
	2	1	38,448	0,019	38,440	0,018
		2	38,392	0,017		
		3	38,423	0,018		
		4	38,462	0,019		
		5	38,476	0,019		
	3	1	37,867	0,018	37,989	0,017
		2	38,011	0,018		
		3	38,018	0,016		
		4	38,018	0,016		
		5	38,033	0,017		

CONCLUSIONS

The results of dynamic tests of TPKM samples are presented. The natural frequencies and damping coefficients for titanium-polymer composite material samples were found. To

determine the natural frequency of vibration for each test, the coefficient of variation did not exceed 0.35%, and for the damping coefficient, the coefficient of variation did not exceed 5%.

The study showed high stiffness of the titanium-polymer composite material in comparison with alumina-glass plastic. On average, the level of damping coefficient of titanium-polymer composite material was ~50% higher than that of alumino-glass plastic. [4].

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Study of Dynamic Characteristics of Hybrid Titanium-Polymer Composite Materials

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