ABSTRACT OF THE DISCLOSURE

A filament wound structure such as a compressor and the method for producing the latter in which a pair of compressor blades is formed by means of a continuous filament in which each filament turns an angle greater than 45°. Each pair of compressor blades is made as an integral unit and secured around the periphery of a filament wound disc. A shroud comprised of filaments is wound and secured to the tips of the blades to form a high strength compressor assembly free of internal stresses.

In the prior art molding of a single high performance filament-reinforced-plastic structure, such as an aircraft compressor blade, the filaments at the blade tip or root have been either discontinuous or bent sharply on a small radius. If the filaments are discontinuous, such as when individual unidirectional fabric plies are placed into a compression mold, the final structure has proven to be weaker than continuous filament wound structures.

If, on the other hand, the filaments are continuous at the blade tips and roots, the sharp bending radius required to form a relatively thin blade tends to produce filament abrasion, breakage and a great deal of difficulty is experienced in trying to maintain the tension of the filaments uniform and at the proper level in the area of the sharp bend. A prime failure mode has been a tensile failure at the blade root, which points to the factors discussed above and to the problem of joining the blades to the other structure such as a disc without introducing localized excessive stresses at the joint. Others have tried to circumvent the problem by using a small diameter metal rod, wound into the root of the blade, however, the latter technique has not proved to be successful because the radius of curvature of the filaments was too small whereby poor control of filament tension and interfilament abrasion resulted. My invention has greatly improved the techniques of the prior art by producing a basic multiple blade structure with better filament control during molding, and better capacity to eliminate high-localized-stress-failure-initiation points.

A number of high strength filaments are currently available, including whiskered graphite, graphite, S-glass, boron, silicon carbide, E-glass, and carbon. The function of the matrix of a composite material is mainly to transfer the stresses onto the high strength filament, and to separate the filaments to prevent interfilament abrasion and breakage. Metals, ceramics, or plastics can be utilized as the matrix, with the latter being the preferred matrix for my invention. An epoxy resin has been the main tested material. For higher temperature applications, above 500° F., another resin such as a polyamide or polybenzimidazole may be used.

The use of filament reinforced composites is growing rapidly because of their extremely high strength-to-weight ratio. The standard filament has been E-glass, with a tensile strength of 500,000 p.s.i. and strength-to-density ratio of 3.4 million. S-glass has a ratio of 7.8, boron 5.4, and graphite 4.9 million. The ratio for the highest strength steel is 2.1 million. In most aircraft structures, the stiffness or modulus is a critical factor.
utilizing a continuous filament by using the techniques of my invention. The blade subassembly 10 includes a pair of blades 11 and 12 respectively which are integrally joined at their respective upper tip and lower root portions by interconnecting members 13 and 14. The subassembly 10 forms a unitary filament wound molded structure of extremely high strength and in which internal localized stress-failure-points are virtually eliminated.

The blade subassembly 10 is preferably formed by winding a continuous loop of filament such as S-glass or any other filament material on a mandrel or shaft so as to provide the necessary predetermined spacing between the blade sub-assemblies from each other so as to provide the necessary predetermined spacing between the blades which is generally the same dimensions as the mandrel 15 if equal spacing between the blades is desired. The latter step is repeated until the desired number of blade subassemblies are completed necessary to form the rotor or stator stage of the compressor. The subassembly 25 whereby the winding is continued forms a unitary filament wound molded structure of extremely high strength and in which internal localized stress-failure-points are virtually eliminated.

An inner disc ring 24 formed of metal or other suitable material is wrapped with a continuous filament over its circumference and then impregnated with a resin. Alternatively pre-impregnated tape can be used and heated sufficiently to form an uncurved resinous mass. The previously wrapped mandrels 15 which have been joined together to form a circle are bolted to the flanges 17a on the inner ring 24 or are otherwise joined thereto in any other known manner. The wrapped mandrels 15 are placed on the circumference of the ring 24 before the resin has cured so that the blades will be firmly bonded to the filament wrap on the inner ring 24.

Side plates 26 and 27 are clamped to the opposite side surfaces of the wrapped mandrels which have been joined around the ring 2 as shown in FIG. 6. A shroud 28 is formed between the side plates 26, 27 by wrapping a continuous filament or by adding pre-impregnated tape having unidirectional filaments therein and modifications of the faces of the side plates 26 and 27 to a depth of approximately 3/4 inch. The top interconnecting portion 13 of each blade wrapped on a mandrel is thereby integrally joined to the shroud. The resin is, of course, in the uncured state immediately after the wrapping is completed and is allowed to cure so as to bond the interconnecting portions 13 to the shroud 28.

An alternative method of applying the shroud is to use a mandrel 15 having integral extended wall portions 25 which are essentially walls of approximately 3/8 to 3/4" thickness. The filaments or pre-impregnated tape is then wrapped between the wall portions 25 whereby the wall portions serve as guides for the filaments. The end plates 23 can similarly have wall portions 25 applied thereto if it is desired to have a continuous wall circumfering the outer periphery of the turbine.

The compressor assembly is now cured in an oven. A typical cure cycle time is a successive treatment of approximately 3 hours at 180° F., 1 hour at 250° F. and then 1 hour at 350° F. After cooling the assembly to room temperature, the side plates (if the latter are used) and the segmented mandrels are removed. A mold release is applied onto the mold parts to facilitate disassembly. The result is a finished disk and blade assembly comprising either a rotor or stator stage of a compressor. If required by the duty cycle of the blades an erosion resistant coating, such as polyurethane may be applied. The resulting structure is extremely strong and because I have eliminated all discontinuity in filaments and I have eliminated all sharp radius turns by forming a two bladed subassembly, there are no areas of localized stress built into the compressor structure, and the blades can withstand a high degree of vibrational, torsional and impact stresses.

While I have shown and described a particular embodiment of the present invention, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the invention in its broader aspects. It is therefore contemplated in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A method for forming a multi-blade turbine comprising the steps of,
(a) wrapping a filament coated with resin continuously around a mandrel having faces thereof shaped to conform to that of compressor blades and other faces shaped to permit said blades to be interconnected by said filament,
(b) connecting the wrapped mandrel to an end plate, and
(c) repeating the step of connecting the wrapped mandrel to an adjacent end plate until a closed circle of interconnected wrapped mandrels and end plates are formed,
(d) applying a filament coated resin continuously around a disc having joining means thereon,
(e) connecting the circle of mandrels at points along its inner diameter to the disc containing an uncured resin thereon,
(f) applying a filament coated with resin along the outer circumference of said mandrels so as to form a shroud,
(g) permitting the assembly to cure, and

(h) removing the mandrels, and the disc after the assembly has cured.

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