More Mileage Than Programmed From Military R&D

Dr. Alan M. Lovelace

An expensive high-temperature and corrosion-resistant cobalt-base super-alloy developed by the Air Force to solve a serious propulsion problem was the only material that a fountain pen company found satisfactory for making the snorkel tube in its pens.

A sealant developed by the Air Force for application to joints to prevent fuel leakage in integral fuel tanks in military aircraft has been used extensively for sealing windows in modern all-glass office buildings. Another commercial application of this same material is the sealing of lapstrake and other joints in wooden-hull pleasure boats.

The Air Force development of a di-3-ethyl-hexyl-sebacate high-temperature synthetic oil, considered a breakthrough in engine lubricants a few years ago, is now available commercially in small cans as a lubricant for washers and driers and, in modified form, as a high-grade gun oil.

Polyester-cotton blends, developed originally for Air Force summer uniforms, have become the leading man-made fibers for wash-and-wear garments. Synthetic mouton fur, designed for military arctic wear, has also found its way into the civilian wardrobe in such forms as coats, coat linings, and collar materials.

These are but a few of a great number of Air Force materials developments that are proving invaluable in civilian applications. The Air Force Materials Laboratory (AFML) at Wright-Patterson Air Force Base, Ohio, had a predominant role in the development of these materials. The AFML is the principal Air Force Systems Command organization charged with planning and executing the USAF exploratory and advanced development program for materials. It also manages the entire Air Force Direct Manufacturing Methods Program.

Usually, once a material is developed and becomes available commercially, tracing it in the myriad products manufactured for civilian use is extremely difficult. Commercial aviation has probably received the greatest benefit from the fallout of Air Force materials research and development and is the easiest area in which to trace a material because of the close similarity of environmental conditions and patterns of usage. Many airframe and engine alloys, protective coatings, greases, fluids and lubricants, elastomeric materials, adhesives, etc., being used in commercial planes are the direct result of programs conducted by the Air Force for military purposes.

PBI

Pioneering polymer research conducted by AFML scientists resulted in a novel approach to polymerization without formation of undesirable weak links in the polymer chain. One of the first polymers made by this approach was the polybenzimidazoles, or PBI polymers.

Increasing requirements being levied by the Federal Aviation Administration for nonflammable materials in items such as upholstery in commercial planes will undoubtedly lead to extensive use of PBI fiber.

As a result of AFML programs to develop the potential of PBI, re-entry drogues, booster recovery parachutes, ballistic capsule recovery parachutes, tire reinforcements, and a wide variety of expandable structures became available with an increased temperature capability of more than 200°F. Yarns made of high-temperature-resistant PBI fibers were successfully transformed into fabrics, webbings, tapes, ribbons, and sewing thread suitable for use in supersonic and hypersonic decelerators.

Further research revealed that PBI fiber is nonflammable in air and in an oxygen-rich environment. Fabrics previously used for aircrew clothing, emergency escape systems, and cockpit and cabin equipment included nylon, cotton, and Nomex, which burn or melt or both when exposed to flame. Characterization investigations on woven and knit fabrics made from staple and continuous-filament PBI fiber demonstrated that these materials are nonflammable and, in addition, are abrasion-resistant, can transmit moisture as well as cotton and therefore offer comfort equal to cotton, and are more heat resistant. These results formed the basis for the development of a number of clothing and hardware items that are already in use or in the process of being evaluated for use not only by the Air Force but by the Army, Navy, and National Aeronautics and Space Administration as well.

NASA has made extensive use of PBI fiber in the Apollo missions. PBI webbings, tapes, ropes, fabrics, and sewing threads were used in the Apollo command modules and lunar excursion modules (LEM). In all the Apollo missions the crew restraint system, in-flight exerciser, debris netting, and helmet and tiedown straps were fabricated from PBI. Although previously available Beta glass materials are nonflammable, PBI provides abrasion resistance and fold endurance not available from Beta materials and is also lighter in weight. In addition, the higher elongation or stretch in PBI fibers results in webbing with greater energy-absorbing capability than is attainable with Beta glass or even metal fibers. The Apollo XI lunar excursion module had a PBI crew restraint system, and PBI rope was the means of conveying the sample boxes from the lunar surface to the LEM.

Experimental items made of PBI fiber that are currently being evaluated include complete personnel parachute packs and harnesses, flight suits, flight gloves, underwear, cushion covers, bunk covers, and sheets.

This material will undoubtedly find innumerable applications where nonflammability is desired. In addition to extensive use in commercial planes, it has a potential in clothing for firemen and race car drivers.

titanium

The Materials Laboratory was instrumental in the meteoric development of the metal titanium from a laboratory curiosity until the late forties to a readily available material of wide applicability. Titanium was exploited as an airframe material because of its high strength-weight ratio and great corrosion resistance. Its high cost has limited its application both militarily and commercially, but if the cost pattern follows that of most other metals, industry will find a way to reduce this cost. As an example, aluminum and platinum were once competitive in price.

magnets

After several years of research, the first "super" magnet is about to be put to use. In 1966 scientists of AFML measured and reported the outstanding magnetocrystalline anisotropy of YCo_5 (yttrium/cobalt) and detailed the basic fabrication techniques that could provide permanent magnets of record properties from a large family of compounds of light rare earths and 3d-transition metals (the RCo_5's, where R is yttrium, cerium, praseodyminum, or samarium). As this program continued, samarium-cobalt magnets were developed to the point where their properties make them far superior to magnets of all other materials for most applications.

Initially, a samarium-cobalt magnet will replace platinum-cobalt in traveling-wave tubes where it not only does the focusing much better but is much cheaper. Moreover, its energy product is two to three times greater than that of the alnicoes, with usable coercive forces up to ten times greater, making it possible to replace alnico in many applications with less material, thereby saving space and weight. Also, the extremely high coercive force of samarium-cobalt makes possible application of permanent magnets heretofore considered impractical. Only very recently have engineers begun to appreciate the potential of this material for devices such as motors. These are the only materials other than the ferrites and platinum-cobalt that are really "permanent" magnets (immune to self-demagnetization for any shape). This is particularly important to dynamic applications such as electric motors and generators.

These magnets will have direct application to electronic and communications equipment and will permit more precise, more rapid, and more reliable computerized techniques, particularly in automated and machine processes.

foam helmet liner

A life-support item that recently evolved from an AFML in-house program was the development of a foam formulation and procedures for the economical fabrication of form-fitting helmet liners. An ill-fitting helmet causes headaches and skin irritation and does not provide proper protection.

The technique in use for fabricating a form-fitting helmet liner for aircrew personnel is laborious, time-consuming, and costly. It entails making a plaster cast of the individual's head and then using it to make a plaster reproduction of the head. The plaster model is then placed in a special helmet mold, and a polystyrene-foam liner is made. This liner will conform to the head exactly. The procedure takes 47 days and costs around $85.

The technique developed by the AFML involves a foam formulation that is notable for an unusually low exotherm (heat generation) and an optimum viscosity and reaction rate for foaming the liner in a special mold fitted right onto the individual's head. With this procedure the form-fitting liner is made in several hours and involves about 25 cents worth of chemicals. The simple procedure can be readily performed worldwide and thus be available to all aircrew personnel.

Inquiries concerning this technique have been received from manufacturers of football helmets, motorcycle helmets, and baseball caps.

The area of plastics and related composite materials represents an extremely broad activity in which the Materials Laboratory has had and continues to have a primary leadership role. As early as 1941 the laboratory expended considerable development effort on plastic resins and glass-fiber reinforcement materials. AFML personnel were concerned with both transparent and structural plastics, and although they did their utmost to stimulate interest in the use of these lightweight materials, application during World War II was limited to glass-fiber-reinforced plastic radomes. As a result of AFML persistence, interest in plastic materials for structures has increased greatly since the war, and according to the August 3, 1970, issue of *Barron's:* "When Pan American World Airways put into commercial operation its first jumbo jet, the Boeing 747, earlier this year, it carried aloft an estimated 10,000 pounds of plastics, more than had ever been used in airliners."

adhesive bonding

The laboratory has done much work on composites, those hybrid materials formed from two or more distinctly different materials that cure intimately bonded together in a deliberately oriented manner. The laboratory demonstrated use of plastic resins as metal-to-metal adhesives, and subsequent military applications proved that adhesive-bonded structures can be stronger, lighter, and more fatigue-resistant than other forms of joining. Leading automobile manufacturers have tested adhesive-bonded car doors that withstood four times as many slams as spot-welded doors. Aluminum storm doors are another adhesive-bonded product.

The field of fiberglass-reinforced adhesive-bonded products for both military and civilian purposes is extremely large, and growing. One producer of fiberglass advertises that it is now being used in more than 33,000 products. Considerable strength is achieved in composite materials by precise orientation of the reinforcing fibers. As a means of producing simple structures with controlled fiber orientation, AFML developed a filament-winding technique to fabricate high-strength fiber-reinforced rocket motor cases and pressure vessels such as oxygen bottles. Filament winding is ideally suited for making cylindrical shapes, and in view of the corrosion-resistance of fiber-reinforced plastics, this method has found civilian application in filament-wound pipes.

heat-sensitive dyes

The Materials Laboratory demonstrated that heat-sensitive dyes can be used to indicate appropriate processing conditions for making reinforced plastic parts. This is an extremely significant development inasmuch as there was previously no nondestructive technique available to determine if time/temperature curing cycles used in making plastic pans were correct. The heat-sensitive dyes are mixed into the plastic resins in very small fractions (less than one percent), and time/temperature integration can be determined by the color changes that occur. A great deal of interest in this technique has been demonstrated by industry, and the AFML is cooperating with a number of industrial concerns to evaluate the process for their use.

Heat-sensitive dyes can also provide a nondestructive inspection technique to determine defects in plastic composites. A phototropic paint, white in color, is applied to the surface of the material. Upon exposure to ultraviolet light, the paint changes to violet color. Subsequent application of heat bleaches the paint from violet to the original white. However, defects or foreign matter interferes with heat transfer, and the paint in these areas remains violet, enabling visual observation of defects.

No less than twenty-three aircraft companies are presently investigating the use of phototropic paint for detecting voids and debonded areas in honeycomb-core composite material. Other potential applications are to determine the integrity of brazed sections in abradable jet-engine seals and other jet aircraft engine components; the adequacy of the bond between composite brake shoe linings and steel brake shoes; the adherence qualities of ceramic paints applied to kitchen appliances (stoves, refrigerators, automatic clothes driers, etc.); and the adequacy of the bond in plastic/metal laminates for underground electrical conduit applications. The phototropic paint, which is an AFML formulation, is being manufactured commercially.

structural composites

Considerable progress has been made in the development of structural composites. These advances are the result of government and industry effort, both of which were spear-headed by AFML. The materials development field has seen rapid growth in the production and quality of reinforcing filaments, primarily boron and graphite. Sufficient boron production capacity has been developed to make systems application of boron composites a near-term reality. Inherent also in the capability to produce advanced composite structural hardware is the requirement for large quantities of high-quality resin-preimpregnated tape, and this capability has been developed for boron/epoxy. The need for composite materials with specific performance characteristics beyond epoxy composites resulted in development of high-temperature organic-matrix and metallic-matrix composites. Boron/polyimide fan blades with a 500°F temperature tolerance have been fabricated and will be evaluated for use in an advanced supersonic turbine engine—just one potential application for this material. The metallic-matrix composites have been demonstrated in such applications as the boron/aluminum missile payload adapter, which was successfully fabricated and tested. Fan blades from SiC-coated boron filaments in a titanium matrix have been produced, raising the temperature tolerance for composites to the 1000°F range.

Production-oriented fabrication techniques are being developed which will reduce the cost of finished composite structures while improving reproducibility and reliability. High-speed, numerically controlled machines are now in operation. The use of these machines, as well as other improved fabrication techniques, will reduce the amount of hand labor required to make composite structural components, thus making high production rates of accurate parts economically feasible.

Designed structural development activities have emphasized the application of analytical techniques and experimental verification to upgrading the understanding of the structural performance of advanced composite materials. Typical of this activity are the continual growth of the engineering data base and the compilation of engineering design information in reference documents for government and industry application. This growth in the understanding of the performance of materials has resulted in solutions to specific technological questions. A wing-to-fuselage attachment fitting has been developed based on design concept evaluation for a V/STOL aircraft wing. The successful fabrication and test of this joint specimen graphically demonstrated the capability of advanced analytical techniques to impact on and improve the design of very complex composite structures. Composite analytical techniques, with emphasis on computer technology, are continually improving and expanding to include more sophisticated structures.

A great variety of prototype hardware has been fabricated under AFML contract or through industry-sponsored efforts in cooperation with AFML. In-service evaluation of these structures on an experimental basis has established technological feasibility and has confirmed that substantial weight savings and performance improvements can be achieved through the use of reinforced composite materials. Long-range projections indicate that advanced composite aircraft structures will not only be vastly superior in performance but also may cost less than conventional aluminum aircraft structures. It is logical to surmise that this new technology will find wide application beyond the military market.

Much AFML effort is based on original and pioneering research that establishes feasibility and the fundamental technology for broad areas of development. Civilian and military personnel number slightly over 400, with nearly 75 percent in the professional category. The laboratory has an average of 70 in-house projects, which represent about 40 percent of its total man-years. The in-house efforts keep AFML scientists ahead in their professional area and provide a technological base line for contracted programs. This enables them to select those contractors who can contribute most significantly to the advancement of materials and manufacturing technology. AFML scientists are encouraged to publish the results of their work, and during 1969 a total of 54 in-house reports and 118 journal articles, books, and patents covering AFML programs was published. This was in addition to the technical reports on contract programs.

AFML personnel are extremely active in the materials-related technical societies, and during 1969 they presented 179 papers based on Materials Laboratory programs at technical society meetings. Close ties are also maintained with the academic community, and during the 1969-70 academic year fourteen AFML scientists taught graduate-level materials-related courses at five area universities. In addition, AFML technical personnel have presented a great number of lectures related to materials technology at universities throughout the United States and abroad.

The laboratory supports six information analysis centers, which have been designated officially as Department of Defense centers: Air Force Machinability Data Center, Defense Ceramic Information Center, Defense Metals Information Center, Electronic Properties Information Center, Mechanical Properties Data Center, and Thermophysical Properties Research Center. It also operates the Aerospace Materials Information Center, which provides data on those materials not specifically covered by the other centers. The services of these centers are available to government agencies, government contractors, subcontractors, suppliers, and such research institutes and universities as are in a position to aid the defense posture. Thus every effort is made to disseminate the results of the AFML research program, thereby promoting the rapid utilization and expansion of materials technology by both the military and civilian communities.

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