

Physics and physicists, as this article demonstrates, are sometimes usefully employed in enterprises even so far removed from the world of mesons and nuclear forces as that of textile technology.

By Rogers B. Finch

CIVILIZATION is reported to have existed for some 6000 years. During this period, man has been occupied with the problems of feeding, clothing, housing, and protecting himself by making better use of the elements of nature he found so abundantly around him. Not everyone agrees that over the centuries he has done this in a manner which has achieved for him peace, happiness, independence, and security for which he has struggled. Without adding to this argument, one can at least say that during this period man has developed the physical arts to a very high degree. The most remarkable advances in the physical arts have occurred during the past 300 years, the period to which is credited the birth and growth of scientific thought. A quick glance at the last 30 years of the physical arts would lead one to the conclusion that their development has been taking place on an exponential time scale. Only the most pessimistic among us would conclude that the rate of further development must soon slow down. In any event, we would all agree that developments in basic science during the past few years have opened the way to developments in the physical arts which, but a few short years ago, would have seemed unlikely, if not impossible, to all but the most optimistic.

The Textile Art

In just one of the physical arts, the field of textiles, may be found a vivid example of how much civilized man has been able to achieve through his ingenuity and his ability to pass his knowledge from one generation to the next. The history of the development of the textile art is as long as the history of civilized man itself. It is a fascinating history in that it is a direct outgrowth of man's desire for clothing and shelter, his desire for artistic expression in fabrics used for religious as well as personal purposes, and his need for materials such as ropes, tents, and fishing nets to assist him in his struggle to sustain and protect himself.

Thousands of years have separated each significant change and improvement in the art. Thus, the evolution of the art was exceedingly slow. Then, at the beginning of the era represented by the past 300 years, events took place which, in comparison with the state of the

textile art of the day, were revolutionary. As a manual art, the textile art had probably reached its highest possible development. Yet, with the invention of the spinning mule, the power loom, the carding engine, and the cotton gin, a far-reaching and highly developed hand industry was transformed in the space of a few short years into a highly mechanized industry. Today, the industry is one which is of primary rank. It is the result of the era in which the textile craftsman, the inventor, and the engineer combined talents to produce an industry which is a tribute to man's mechanical ingenuity. Yet, one must realize that there are vast areas of this world which have been completely uninfluenced by this mechanical revolution. The hand textile industry exists in these areas today at the level of development that existed 300 years ago in those countries which have been able to fully exploit the mechanical revolution.

The textile industry of twenty years ago represented a combination of art and invention which was truly remarkable. The achievement was principally that of mass production without an appreciable change in the basic operations which must be performed in order to convert a fiber into a decorative or utilitarian material. The engineer and the chemist with their specialized knowledge and skills are responsible for this conversion of textiles from a craft to a modern industry and are now considered indispensable to its operation and growth. On the other hand, this type of progress has not obviated the need for some of those men and women who, through long experience as apprentices to skilled craftsmen, know by touch, sound, feel, smell, sight (and extra-sensory perception, if you will) how to make textiles of high quality.

Textile Science

The role of science had been an indirect one in the period prior to the last twenty years. The development of mechanisms, power and its distribution, and metals for machinery have all benefited the industry. However, it is only during the past twenty years that a distinct textile science, capable of justifying its being dignified with the name, has developed. This has come about because of the great need for studying the ma-

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materials themselves, their properties, and how they should be handled in making them suitable for their intended uses. The reason for textile science arising as a definable field of applied science is that only a combination of the basic scientific disciplines could meet this need. This development has been greatly accelerated by the discovery of the laws of polymerization in the thirties and the rash of man-made fibers (whose listing is outdated as soon as it is compiled) that has resulted. In fact, textile science has been outpaced by the development of fibers to the point where the fiber manufacturers are begging the textile industry to tell them what fiber properties they need. Textile science has not yet progressed to the point where this can be done on an entirely quantitative basis.

Chemical Physics

Consider the variety of techniques which textile science must employ in studying the structure of the textile fiber. As a high-polymeric organic solid, its structure must be represented in terms of the placement of atoms and atomic groups along the molecular chain, the occurrence and nature of cross-linkages, the space lattice structure of the micelles formed at intervals along the chain with other molecules, the thermodynamic state of the aggregate, the molecular forces acting between components, the formation of a molecular network into fibrils in natural fibers, the placement of fibrils in the fiber as a whole, and the internal and surface discontinuities of the fiber. All of these considerations bear on the mechanical and optical behavior of the fiber. Few of the elements of its structure can be directly measured with high precision. Knowledge of its structure must be inferred from chemical analysis, x-ray diffraction, electron microscopy, swelling in various reagents, optical birefringence, specific heat, mechanical behavior, selective placement of dye and other molecules through use of radioactive tracers, heat transfer properties, dielectric properties, and other phenomena. The interpretation of all of these must be tempered by statistical analysis because of the variability of the structure and, as a consequence, its physical behavior.

The physicist possesses much of this additional

knowledge needed for a solution to the problem of fiber structure analysis and behavior. This fact has been given greatest recognition by the synthetic fiber producers. The introduction of the physicist into textile science, since the miraculous (if accidental) discovery of nylon, has facilitated the development of many widely different new fibers. It is not generally appreciated that for every new fiber introduced into the textile industry, the fiber producers have conceived, tested, and rejected hundreds more. These tests, although rejecting fibers which were unsuccessful from the textile point of view, are being thoroughly studied in each instance to determine what structural modifications must be made in order to obtain a fiber which would have desirable textile use properties.

Although our knowledge about the relationship between fiber structure and mechanical properties is increasing, the measurement of these properties and the determination of their correlation with use behavior govern the usefulness of the knowledge. Unless the properties measured can be used to predict use behavior with greater precision, extensive and costly full-scale industrial evaluation must take place. The growing success of the prediction process may be seen in the fact that the number of fibers which reach the industrial evaluation stage are becoming a smaller percentage of the rapidly increasing number of fibers which emerge from the test tube.

Instrumentation

Laboratory measurement of mechanical behavior has been greatly improved during the past decade through two significant developments. The first was the recognition that textile fibers have a unique mechanical behavior. When placed under load, they extend at a decreasing rate with no further increase in load. This creep effect is different at different temperatures, relative humidities, and rates of loading and is also dependent upon the whole previous history of the conditions of stress, strain, time, temperature, and relative humidity to which the fiber has been subjected. A

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study of these relationships has made it possible to understand what has been referred to as the "perversity of inanimate objects." It has given the textile science team a basis for understanding the complex realm of the stress-strain behavior of fiber, yarn, and fabric in tension, torsion, compression, impact, shear, and complex combinations of these effects for various lengths of time and under varying atmospheric and geometrical structural conditions.

The second development which has made the precise measurement of these properties possible is the use of electronics in physical measurements. Stress transducers combined with high-speed recorders have made it possible to make rapid and precise measurements of these physical quantities. Acoustical pulse techniques for the measurement of sonic modulus have made possible the separation of the immediate elasticity component from the recoverable and irrecoverable creep components of stress-strain behavior. Many of these techniques have long been familiar to the physicist but his knowledge has only recently been utilized by textile science.

Geometrical Structure

Fibers are only the first element of structure of a textile material. They are twisted into continuous yarns. The yarns are woven, knitted, or otherwise formed into fabrics and the fabrics are made into a variety of physical shapes. It is the behavior of these physical shapes which is the ultimate criterion of textile performance. This means that the relationships between fibers in yarns and between yarns in fabrics must be understood if satisfactory textile performance is to be predicted with precision. In this study, the macroscopic considerations of mathematical placement of structural elements and their physical interrelationships become of paramount importance. It might be thought that this is a problem for the structural engineer. If the engineer of today were better acquainted with the realm of applied physics and, more specifically in this field, with the behavior of organic high-polymers as structural materials, then this would be so. However, the physicist best meets this specification today, although the modern young physicist seems to be too enamoured of the field of electronics or nuclear physics to wish to apply himself to anything as apparently unchallenging as the field of textile materials. The fact remains that textile science needs the physicist to fill this gap in its study of textiles from the molecular aggregate to the final textile structure.

Industrial Measurement and Control

Modernization and improved control of the industrial processing of textile materials has been brought about through the application of many developments in the field of physics. Industrial rule-of-thumb, necessary in bridging from the home craft to modern large scale production, is being replaced by more and more complete mechanization and scientific control. For example, the control of moisture in materials about to be pack-

aged for shipment from the textile mill is such an important economic factor in the relatively low margin textile industry that changes of a few percent may mean the difference between profit and loss. The fact that small changes in moisture content produce relatively large changes in the dielectric constant of textile fibers has made it possible to develop a measuring device which continuously monitors the capacitance of material being dried and automatically adjusts the dryer through a servomechanism to produce the correct moisture content within the acceptable percentages.

Where the process calls for precise determination and control of thickness, a beta-radiation instrument is now employed. For example, the thickness of plastic coatings on fabrics for industrial uses must be precisely controlled. The coated fabric is continuously monitored by an instrument which contains a source of beta-radiation carefully calibrated for this material. A minute change in thickness produces a change in the absorption of the radiation. This change is amplified and quickly adjusts the coating process through a servomechanism until the thickness is again correct.

Studies in lubrication and friction are permitting the design of machinery which operates faster and longer. The possibility of electrostatic and aerodynamic placement of fibers in yarns promises ultimately to revolutionize and simplify the present complex of textile operations. It is now possible to separate and move fibers selectively by these means but no one can yet say exactly how the fibers should be recombined to produce yarns with particular properties.

Color

One of the most interesting applications of physics has been in the field of color specification, analysis, and control. The ancient textile colorists were not concerned with being able to produce identical shades of color in successive lots of material. The techniques of producing color and color combinations developed over many thousands of years and were passed along to each successive generation of craftsmen. The Industrial Revolution brought with it the concept of mass production. This forced the textile industry to give greater attention to the specification of color. Successive dye lots now had to match within the ability of the human eye to detect differences. This requirement has given rise to an extensive study of the physical and physiological aspects of color difference detection.

One amusing situation recently arose from a study of the color response of a group of color television research engineers employed by a well-known company. Tests showed that a large percentage of them had some form of color blindness. Perhaps the recent controversies over color systems was a partial result of this problem.

In textile coloring the problem of the detection of color difference is complicated by the fact that human beings differ widely in their abilities to detect the kind and degree of color difference. Nevertheless, the textile colorist must be able to reproduce a given color

on a large scale with such precision that even the most discriminating observer will be unable to detect any difference between adjacent pieces in a garment when these pieces come from bolts of cloth which were dyed at different times. The industry has bred some very skilled color matchers. Their problems have been greatly complicated by the development of a variety of types of artificial illuminants. The traditional practice of observation under "north light from a partially overcast sky in the temperate zone in winter" is no longer good enough. Pieces of colored material must be capable of matching under the widest variety of illuminants. The color matcher is under the additional handicap of being an observer after the fact. The material is already dyed and he can only inform the boss dyer that what he has just dyed is right or wrong. The correction of color errors is an expensive process, particularly with today's fabrics being turned out at very high rates in a highly competitive market.

The physicist has recently entered on the scene with his knowledge of the physics of color and his development of the concept of tristimulus values for color specification and spectrophotometers and colorimeters for color analysis and control. A physicist on the management staff of a well-known carpet company has put many of the principles of color measurement, specification, and control into industrial practice with outstanding results. He has developed the science of pre-mixing of dye-stuffs on a large scale to the point where only a small range of basic colors is needed to reproduce anything from "midnight azure" to the current shade of "shocking pink." The old color range sample room with its aged and dirty standard color samples is disappearing and its place is being taken by the file card with unchanging tristimulus values.

The textile industry has recently created additional problems for the color physicist. For example, the development of fluorescent dye-stuffs has produced considerable consumer interest in a wide range of effects obtainable with such colors. When fabrics dyed with these colors were first examined with the spectrophotometer, the instrument was baffled by the fact that the reflectance energies measured were higher than the energy of the light source. Entirely new principles of measurement have, as a result, had to be developed. Military fabrics require colors which will camouflage the wearer. The development of infrared detecting instruments has made it necessary to extend the principle of camouflage beyond the visible color spectrum.

Physiology and Textile Science

There is increasing interest in the relationship between the properties of textile materials and their use as a human protective covering. The main principle of clothing design in the past has appeared to be based on what the designers say is stylish, rather than on what is both stylish and comfortable under various climatic conditions. The physicist has now been asked to assist in determining the relationship between atmospheric stresses and human comfort. His work in solar radia-

tion, heat transfer, vapor permeability of solids, heat and moisture measurements, and micro-climatology (next to the human body) has been combined with that of the physiologist and the engineer to determine the basic principles governing the use of textiles as protective materials.

The Textile Science Team

The primary task which faces textile science is that of understanding the "whys" of the present state of the textile art. Man has been using satisfactory textiles for centuries without understanding how he has accomplished it. The chemist was probably the first member of the textile science team to apply his knowledge to a portion of this problem. He has studied the structure and chemistry of fibers, and the chemistry of the coloring materials which man has used over the centuries to enhance the appearance of his textile materials. The chemist developed the synthetic dyestuffs industry to the point where these coloring materials are now used almost exclusively in the modern textile industry.

The role of the biologist, the engineer, and others may be similarly described but it is the addition of the physicist to the textile science team which promises to make that team more completely effective in pursuing its basic problem of providing a quantitative approach to the understanding of the textile art. Textile science looks to the physicist to assist in building the springboard from which it may leap beyond that point to which the textile artisan has been able to bring his craft but at which he finds himself limited by his lack of facility with scientific method.

During the past twenty years, the physicist has been highly effective in unlocking the secrets of the structure of matter and other phenomena of nature through the application of new scientific techniques. Application of this knowledge is making it possible to study the structure of textile fibers in order to obtain a better understanding of why they behave as they do. It has also opened the door to methods of designing fibers with predictable properties.

The textile industry has long ignored the specialist in solving its problems. It has favored the "generalist" or "textile jack-of-all-trades." Its progress is dependent upon the use of the master in each trade, not just by himself, but in combination with each of the other masters to form the textile science team. Just a few textile developments which have been brought about through the specialized knowledge of the physicist member of the textile science team have been cited. An extrapolation of these developments would lead one to conclude that there are many more developments yet to be accomplished as a result of the application of the specialized knowledge of the physicist.

The textile science team needs the physicist, is learning how to work with him, and has come to realize that the future revolutionary changes which are bound to take place in the textile industry will be due in no small part to his contribution.