Bull. Mater. Sci., Vol. 5, Nos 3 & 4, August & October 1983, pp. 373–380.

Materials research at National Aeronautical Laboratory (Contributions of S Ramaseshan)

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Abstract. Materials research programmes of the National Aeronautical Laboratory and Prof. Ramaseshan's contributions to these are presented in this article.

Keywords. Materials research; National Aeronautical Laboratory.

1. Introduction

It is well-known that sophisticated engineering applications of materials result from their properties. Mechanical properties are influenced by imperfections in the crystalline structure of materials. Physico-chemical properties are governed by electronic/atomic/molecular structure of materials. Any significant contribution to a high technology area like aeronautical materials can only arise from an understanding of the properties of materials from a basic scientific point of view. An engineering approach would only be useful to optimize the use of a particular material for a specific application. It cannot pave the way for newer materials and newer applications. It is because of these reasons that when the National Aeronautical Laboratory decided some years ago to initiate Research and Development programmes in materials science, it had to look for a scientist with considerable research experience in fundamental science to organize and lead such an activity.

When it was learnt that Prof. S Ramaseshan (then at the Indian Institute of Technology, Madras) had been invited by the CSIR to organise a Materials Science Research Centre in any one of its laboratories, he was welcomed to join NAL to found the Materials Science Division. Ramaseshan, was known at that time for his contributions in optics and crystallography and his creativity in fundamental science was still growing. He chose to take up the challenge of organising materials science research in NAL and joined as Head of the Division in 1966. Looking back over the last one and a half decades on his contributions, it was one of the most fortuitous but fruitful associations that a growing laboratory like the National Aeronautical Laboratory could have hoped for. Materials research programmes of the laboratory and Prof. Ramaseshan's contributions in respect of these are briefly presented in this article.

2. Organisation of the Materials Science Division

The organisation posed several problems. Qualified scientists and engineers trained in materials science were not available, since the Universities had not started post-graduate courses on materials science and technology. The aircraft industry producing aircraft under licence did not pose any challenging problems. There were no definitive plans for building an indigenous aircraft and hence no particular demand on materials development. This posed the problem of giving to the research personnel the feeling that they are working on useful developments. It was also necessary to see to it that the utilitarian aspect of developmental activity does not take away from it the flavour of research. There was the need to maintain interdisciplinary approach. The research acumen of bright young people had to be kept sharp and alive.

We shall attempt to delineate briefly the approaches made by S Ramaseshan to provide a reasonable solution to this many faceted problem. He took the view that the activities of the division will be broadbased, and will be centred around materials science problems of interest to aeronautics, space and electronics. Even though the objectives were broad, the major thrust was in the area of materials science for aeronautics so as to make the Division an element of NAL.

To instil a feeling of being useful and a sense of accountability in the research personnel and to build their capability to complete the work within the time target, he sought sponsored research programmes, which went a long way in boosting the morale of the personnel. With a view to keep a balance between Research and Development, between being immediately useful and establishing an R&D base for aerospace materials science and between science and technology, he pursued science with a group of research fellows and a few scientists and developed technology with the research staff with an engineering background. He encouraged each group to work parallely on short, medium and long range investigations as well as on problems that can help the group to acquire competence in their area of specialisation and also continuously update their expertise. Every group was encouraged to devote a fraction of their time to ask questions of a basic nature related to their applied activity and find the answers. S Ramaseshan believed that technology is built on science and no worthwhile technology can ever be developed without a scientific approach. To inculcate the scientific spirit in the minds of technologically oriented groups and to prevent the development of ivory tower attitude in those engaged on basic problems of materials science, he deliberately made them interact. Solutions were invited from the research scholars working on basic science, to knotty problems of technology faced by applied scientists, who in turn helped them to build the equipment needed for their work paving the way for the complementary growth of science and technology.

S Ramaseshan gave a great deal of thought to the type of problems that were to be taken up. Should they be related to the development of materials? Should they be on structure-property correlation? He felt that an operational definition of aeronautical materials science must be evolved to formulate guidelines to choose research problems. From a study of the materials that went into an aircraft, he concluded that their cost was between 10–15% of that of aircraft. Developing them and producing them would be more expensive than importing them. By starting on import substitution programmes, he felt we are not closing the technology gap. Besides, it will be difficult to implement import substitution when we have licenced production. Therefore, he took the view, that materials development programme should be launched only on strategic materials on which either there was or is likely to be an embargo, on materials of future aircraft and on materials which are to be produced by a new technology (for instance the ribbon technology for growing single crystal foils). From his analysis he found that fabrication played a major role in the aircraft manufacture. He also saw that assuring quality was much more important in aerospace materials. The above arguments led him to adopt the view that fabrication and testing of materials were part of materials science. He looked upon materials science as a discipline that helped one to realise a product to the required specification, once the design is completed.

With this preamble, we shall proceed to highlight his work in the Materials Science Division of NAL. S Ramaseshan considered composites as a thrust area because of several reasons:

(i) It would be an important material for future aircraft since it has a buy-to-fly ratio (the ratio between the amount of raw material purchased and the amount that actually goes into the structure of the completed aeroplane) of 1·05:1 as compared to a ratio of 10:1 for conventional materials.
(ii) It would be used more and more by non-aeronautics industry because of its strength and excellent corrosion resistance.
(iii) Radical changes in our thinking about materials are likely to occur as a result of the appreciation of the science of composite materials. Even though at the time he initiated work in this most important area, only 1 % of the airframe of a high performance jet plane was made of composites, he intuitively felt that the day is not far off for the appearance of nearly all-composite aircraft. At one time, he suggested that the development of such an aircraft must be taken up as a major task involving all the divisions of NAL. It is interesting to note that around 1975 the US Government studied advanced design composite aircraft (ADCA) and showed that the production costs would be lower by 21 % and fuel savings would be of the order of 30 %.

Steered by his conviction that composites is a material of the immediate future, he not only initiated programmes but also involved himself in R&D work on all aspects of composites such as materials, fabrication by handlaying and winding techniques, winding machines and testing.

When the work gathered momentum, he saw that non-aeronautical industries might start using FRP technology earlier for sophisticated engineering applications. Hence he started a programme on development of products, which would be useful to non-aeronautical industries. This decision is laudable because such an activity can not only result in building competence in the design fabrication and testing of composites but also give to the R&D personnel the satisfaction of seeing the utilisation of their technologies by industries. The most important products developed are: products for communication (radomes, antenna reflectors, radar cabins etc), insulator components (rods, plates and cylinders) for electrical and electronic industries, components and accessories for wind tunnel studies (aerofoil sections, contraction cones, fan blades) radomes for aircrafts, components for space application (rocket nozzle inserts, nutation damper for Aryabhata), components for defence forces as well as defence sector laboratories, containers for transportation of chemicals and cyclone separators for separating corrosive mists from airstream.

Many of these needed a design and development approach. Radomes would be a typical example. In the technology developed, radomes were constructed as a free standing structure from triangular FRP panels with steel ribs along the sides of the triangle for imparting the strength needed to withstand wind loads due to wind velocities of the order of 240 km/hr. Steel ribs gave the strength but scattered the electromagnetic radiation. Therefore, the design called for an optimisation of panel thickness, number and size of ribs. This was accomplished using electromagnetic and wind tunnel test data. The design was evaluated by testing live radome for actual wind loads, by using a static equivalent load representing a dynamic wind pressure. Radomes of 55 ft (16.7 m) diameter were built and tested. It would perhaps be appropriate to mention that a diameter of 55 ft represents practically the largest size that can be built by this technology. Free standing structures larger than this size tend to collapse by their own weight.

A 55 ft diameter radome for the air traffic control radar used by the Indian Air Force has been installed at an altitude of about 8000 ft above the mean sea level near Jammu. Several 22 ft (6·7 m) diameter radomes were installed at various coastal locations specified by the India Meteorological Department for protecting their cyclone warning radars and are functioning satisfactorily.

Another interesting development is the FRP cooling tower fan blades (upto 7·5 m in sweep) which are part of every major thermal power station. These blades consist of FRP skins and polyurethane foamed *in situ*. Their low weight compared to wood results in saving of power. They are free from the problems of warping (exhibited by wooden blades) or corrosion (exhibited by metallic blades). These blades are in use even today in the cooling tower of the wind tunnel of NAL.

FRP tubes with controlled porosity is yet another important product developed. These can be used as structural support for membranes used in desalination plants. This product is likely to lower the cost of desalination plants since they substitute metallic tubes (stainless steel for instance) which are more expensive and difficult to drill accurately.

Development of technology implies its transfer at some stage to industry. S Ramaseshan adopted the stand that involvement of the industry absorbing the knowhow is necessary from the time the knowhow is demonstrated in the laboratory, because Indian industries do not have the capability to productionise a laboratory knowhow and the laboratory scientists do not have the experience in industrial production. As a practical step towards bridging the gap between laboratory knowhow and industrial technology, he started an FRP pilot plant which produced the developed items in quantity and supplied them to the user organisation which is likely to absorb the technology. This brought about an involvement of the user of the technology and resulted in improvements in product/process. This exercise led to the successful transfer of quite a few knowhow. The technologies successfully transferred are the filament winding technology for the manufacture of aerials, masts etc., radome fabrication technology, FRP rain gauges and light weight transportable shelters.

When S Ramaseshan started talking to potential users of FRP materials, there were problems convincing them about the environmental stability of this material. They could not be talked into the use of FRP with data on its stability published elsewhere; because, they had reservations regarding its performance in tropical climate. To generate first hand information so as to convince himself and others, he started a programme on the environmental effects on FRP to study its degradation and predict its service life. On the basis of this study, it was demonstrated that a 15% reduction in strength resulted from the first three years of exposure and thereafter there was no significant loss of strength. On the basis of this data, a service life of about 10 to 15 years (with 85% of the initial strength) was assigned to FRP composites made with different resins. This work which was a valuable spin-off from the design and development of FRP product, is being continued to assess and understand moisture absorption characteristics of resins and composites made from them and is likely to provide lasting solution to the surface degradation of composites.

His preoccupation with the development of FRP composites did not distract him from working on frontier areas in this field. He found that silica fibre, being able to stand a higher temperature than glass fibre, would be useful in developing composites for use as thermal insulation and for ablative application as well. He initiated a programme on the preparation of high silica fibre by leaching with acids, oxides other than silica, which are present to the extent of 45 % in E glass. This programme resulted in the development of high silica fibre which has been christened as 'Nalsil'.

He initiated work on the development of high-strength, high-modulus aramid fibres as soon as du Pont introduced Kevlar-49 because of the potentialities of advanced composites made from these fibres. This work is now beginning to bear fruit.

Many Indian natural fibres like sisal, ramie and jute are twice as strong as glass fibre, have the same modulus of glass fibre and are inexpensive compared to glass fibre. But they absorb moisture and lose their strength. Therefore, he initiated work to improve the moisture resistance of fibres, with a view to develop low cost composites, for less sophisticated applications, with natural fibres available in India.

Besides these, he initiated feasibility studies on the development of inorganic fibres (like basalt, boron and boron nitride), ferrocement, asbestos-cement and metallic composites.

Thanks to his vision and involvement the division has carved for itself a place in the area of composite materials. S Ramaseshan used to remark that the importance of fabrication technology in the manufacture of aircraft by the current technology, is shown by the fact that the buy-to-fly ratio is 10:1 for conventional materials. He therefore encouraged work on machines for fabrication and methods of fabrication.

Bearing in mind the need for unconventional machining methods for modern aero space materials he initiated programmes in this area. Electric discharge machining was one of the programmes taken up by him.

He realised that in this chipless machining method, the subsystem that really needed R & D efforts was the spark generator and not the machine tool. With collaboration from the Electronics Division, the knowhow was developed. EDM machines fitted with spark generators made with NAL knowhow are being produced by the industry.

Work was then initiated on electrochemical machining (ECM) for fast machining of complex shapes in aerospace industries. He felt at that time when precision casting of blades had not yet become an established practice, the manufacture of turbine blades could be considerably speeded up using ECM for rough machining and EDM with electroformed tool for finish machining to dimensions. With this master plan at the back of his mind he embarked on ECM. At a fairly early stage in this activity he got the Southern Railways interested in this technology as a prospective buyer of this technology for the production of nozzle rings of diesel turbo-charger. This development proved to be an order of magnitude tougher than EDM and his efforts are slowly bearing fruit. He also planned to initiate work on explosive forming, electro hydraulic forming etc.

The Raman Research Institute wanted to set up a 10·4 m millimeter wave radio telescope to study the nature and composition of interstellar matter in our galaxy. S Ramaseshan offered to fabricate this telescope which would significantly contribute to the experience in newer fabrication techniques. Besides, the spin-off from this work namely the technology of fabrication of large parabolic dishes, would be useful to the Department of Space, IMD etc.

The requirement is that the 10·4 m parabolic reflector should have an accuracy of 30μ

rms or better and must be capable of dismantling and assembling to yield the same accuracy. The design and development is broadly based on that of Prof. R B Leighton of California Institute of Technology. The interesting aspects of the design are: (a) the dish when inclined to various angles will still be a parabola with a different focus; (b) it permits reassembly to the same accuracy as that of the initial machining, namely better than 30μ.

With a view to communicate the challenge and excitement that this fabrication offers, we shall describe briefly the fabrication technique. The dish is fabricated from hexagonal aluminium honeycomb sandwich panels machined to shape after assembly using an aerostatic bearing for rotation. Aluminium skin is vacuum-bonded to the machined panel, assembled and finish machined. The back-up structure is a net work of struts held at suitable points by pin-joints. This needs posts and struts of various lengths ranging from 500–1200 mm with holes drilled to close tolerances of $\pm 13\mu$.

The radiotelescope is now in the final stages of fabrication. It is a thrilling experience to watch the 5000 kg dish slowly spinning on an aerostatic bearing as the cutter travels down the guide rail machining the dish to the desired contour.

He perceived coatings as an important area since surface properties like hardness, friction, wear, abrasion resistance, absorption of radiation, emissivity, contact resistance etc. could be tailored through coatings. He initiated work on electroplating of metals and ion plating (a modern vapour phase deposition technique). The former was chosen because the coatings could be applied at room temperature with inexpensive equipment. The latter was chosen as a complementary technique to deposit metals that are difficult to be deposited from aqueous baths. The electro-deposition of composites, development of high speed-plating baths, gold plating of magnesium alloys for space applications and plating on difficult-to-plate metals like Al, Mg, Ti, W, Mo etc. are some of the significant achievements of this group.

To win the confidence of aeronautics industry, he took a personal interest in trouble-shooting production problems of HAL involving young research fellows to give them a feel for applied science. He suggested as many alternatives as possible so that the industry can choose the one that can be implemented easily. He investigated the causes of optical distortion exhibited by aircraft cockpit canopies fabricated out of perspex and suggested solutions.

Cracking of stored high strength Al-Zn alloy components, experienced by HAL, was one of the earliest problems he investigated. He found that it was due to stress corrosion caused by locked-in machining stresses and recommended suitable stress relieving heat treatments which will not affect the strength.

As a consequence of this work he perceived the importance of measurement of locked-in stresses and encouraged the development of an x-ray method to determine the same. For a long time HAL used the x-ray stress measuring facility of the Division for monitoring stress levels of machined components.

The *ad hoc* investigations of a trouble-shooting nature acted as a nucleus for the development of failure analysis as one of the important contributions to the aeronautics industry as well as every other industry spreading the message of improving reliability through failure analysis. Today the failure analysis team is one of the most respected groups in the country because of the value of its judgement on problems of failure analysis, accident investigations and materials evaluation.

He initiated programmes on the preparation of crystalline materials such as hydrothermal synthesis of CrO_2 (the material of modern magnetic tapes), single crystal ribbons of silicon (for the photovoltaic conversion of solar energy) and narrowband gap semiconductor infrared photon detectors for the 8–14μ atmospheric "window". Another important work initiated by him was laser-based visual range assessment system for use in airports.

To ensure quality control in aircraft materials, he created infrastructural facilities for chemical characterisation of materials, x-ray characterisation of materials, structural characterisation of materials and mechanical testing of materials. He encouraged the groups working with these facilities to work on R & D problems of characterisation and testing.

Inspite of his preoccupation with materials technology, he found time to pursue fundamental research with a small group of research fellows. His main contributions in this area are given below.

Anomalous scattering of x-rays has been a subject close to his heart since 1957, when he applied anomalous scattering of x-rays for the first time to solve the structure of centrosymmetric crystals. He showed theoretically that anomalous scattering of neutrons can yield information on the polarization vectors of lattice waves and subsequently described detailed experimental procedures for their determination in centro- and non-centro symmetric crystals. He perceived the possibility of using anomalous scattering of x-rays coupled with multiple wavelength method to obtain the structure of amorphous or liquid binary systems. This work has become important with the advent of synchroton x-rays which makes it easy to apply this method experimentally. This method has become a standard tool in structural investigations on metallic glasses. A unified theory of anomalous scattering of x-rays and neutrons was also developed.

Recognising his significant contributions in the field of anomalous scattering, the International Union of Crystallography invited him to organise (in collaboration with S C Abrahams) an International Conference on this subject at Madrid in April 1974.

A theory for the propagation of light through heterogeneous media was developed. Stress-induced optical activity in optically inactive non-centrosymmetric crystal, neutron optical activity of helimagnetic systems and anomalous transmission of certain circularly polarised states near Bragg reflection (Borrmann effect) in absorbing cholesterics were predicted from theoretical considerations.

The concept of ionic radius was extended by introducing the new property of ionic compressibility. Using these two properties a theory of ionic crystals was developed. This theory, unlike the earlier ones has predictive power and has been used to describe a variety of crystal structures *viz.* NaCl, CsCl, sphalerite, fluorites antifluorites, perovskites and inverse perovskites.

An understanding of the protective action of radio protectants in terms of radical scavenging mechanism was gained from a study of the x-ray structures of radio protectants. It was suggested that x-ray radiation damage of proteins during their structure determination could be reduced by diffusing chemical radio protectants in the solvent region of the protein crystal.

S Ramaseshan invited A Jayaraman of Bell Telephone Laboratories to initiate work on high pressure physics and technology, when he found that high pressure behaviour of materials is opening up new challenges and high pressure synthesis of hard materials like diamond, cubic boron nitride is becoming a practical reality. A Jayaraman's collaboration ushered in high pressure research into the Division. He also initiated the fabrication of cubic press. Interesting contributions on the electronic transitions in liquid caesium, cerium and ytterbium were made. A "two species" model was developed to explain the observed variation of resistivity with pressure. Pressure-induced metal-semiconductor transition in ytterbium was shown to be due to the removal of the 6s–5d overlap.

The National Aeronautical Laboratory owes much to S Ramaseshan's vision and leadership in founding and guiding the Materials Science Division and enabling it to grow it into a respectable R & D Centre for materials science and in contributing significantly to its overall growth creative suggestions.