Why are heat treatment and surface engineering important?
INDUSTRIAL AND SOCIAL SIGNIFICANCE

Engineering systems and components are the result of a complex chain of actions, starting with a design to match the functional demands: there are often multiple stages in the manufacturing process, as well as essential quality assurance methods for the component and system.

All steps in the process have their own special significance. Optimum outcomes and cost-effectiveness depend heavily on the way in which they are orchestrated and managed as an integrated sequence. At given times and in given circumstances the relative importance of each step may be viewed differently, but **the heat treatment and surface engineering processes in the manufacturing stage are almost always critical.** While mining, primary extraction and materials production processes have an undeniably macro-scale industrial influence on economics, society and the environment - and they tend to receive most attention in the public media - heat treatment and surface engineering processes actually make machines and systems function. Also, these heat treatment and surface engineering processes themselves represent a complex balance of materials, technology, energy and environmental factors to achieve an optimum combination of industrial feasibility and economic and social viability.

Thus, heat treatment and surface engineering processes are crucial elements in virtually the whole of engineering and manufacturing. They are especially, but by no means exclusively, relevant to metals. A combination of correct selection and control of the processes is essential for the safe, economic, and environmentally acceptable operation of components and systems; this and a proper understanding of them in their engineering context is central to optimum design and performance of components and systems in, for example, vehicles, aircraft, oil rigs, agricultural machinery. The panel on the next page gives an idea of the broad industrial significance.

HEAT TREATMENT

The term 'heat treatment' covers such processes as annealing, quenching, tempering, thermochemical and thermomechanical treatments (forming/shaping during controlled heating). Heat treatment is best appreciated in relation to steel. The outstanding advantage of the vast range of steels as engineering materials is their versatility. By means of heat treatment, one or other of given steel's characteristics can be enhanced; indeed, much of the versatility of steel actually rests on the fact that its properties can be controlled and changed by heat treatment. For example, at its simplest, if a steel is intended for forming into an intricate shape, it can be made soft and ductile by heat treatment. If it is to resist wear, it can be heat-treated to a hard condition. Therefore, although the chemical composition of a steel is obviously important, steel of a given composition can be modified through controlling the nature, distribution and quantities of its constituents. The science of heat treatment deals with the factors and mechanisms involved in this control of composition and properties; the industrial technology of heat treatment processes deals with 'getting it right' economically, operationally, and environmentally.

The term '**surface engineering**', which began to gain global acceptance and understanding in the 1980s, is defined by

IFHTSE as:

‘The use of traditional and innovative surface engineering technologies in the design of a surface and substrate together to form a functionally graded system, which results in the cost effective performance enhancement of materials and components.’

In other words, it is the group of processes yielding an engineering component with certain bulk properties (such as toughness) following heat treatment, and very different and/or graded surface properties (such as high wear resistance) after surface engineering. The diagram on the next page illustrates the general scope.

The processes represent a central element in the making, forming, and processing of materials – originally and especially steel - and they are **increasingly relevant to other metals**, especially aluminium and titanium, **and to non-metallic materials**. Thus the family of processes has expanded so that it is relevant and important to plant and equipment manufacture, engineering materials production, services, fuels, atmospheric gases, and all the associated communities of scientists, technologists, operatives, and their support staff.

This represents a large and diverse population; but the total picture is even more complex. The whole field is characterised by high added value against the background of an ever-increasing pressure to satisfy **environmental and energy imperatives**. The essential periodic injections of good new science in these areas involve materials developments and advances in process and plant design and control. Also, surface engineering is growing in sophistication and variety and much of it is applied at the frontiers of technology. For 30 years, IFHTSE has effectively combined the inputs of materials and mechanical engineering experts, but increasingly wider input is needed, from materials science to new approaches, needs and applications, as indicated in the examples below.

Materials science and materials selection criteria in the manufacture of machine elements are in a constant state of change and development. Heat treatment and surface engineering play critical roles in these changes. For example, advances have been made by using these processes to impart functional capability in demanding situations to a component basically manufactured from a relatively cheap substrate metal, or replacement of steel gears with the relatively lighter and tougher titanium can be made possible by countering titanium’s poor wear characteristics through surface engineering techniques.

Tribology as a concept was briefly described in 1966 as;

‘The science and technology of interacting surfaces in a state of relative motion, and the associated subjects and practices’

This obviously broad scope covers phenomena and processes such as friction, traction, lubrication, and wear, in all mechanical contact situations and at the design stage. From the friction viewpoint, in for example an automotive context, the materials and engineering design may require high levels of friction (in braking systems), or very low levels (piston rings, liners, bearings, gearboxes). The tribological approach is thus concerned with optimum machine design and maintenance leading to optimum service life, efficiency, and operational reliability. A successful tribological approach is critical to the economics as well as the functionality of machines and systems in industrial manufacture and processing. In this way, 'tribology' is often seen as a successful management approach as well as a proper application of scientific principles. However, the application of the tribological approach has been, historically, all too often remedial. If tribological aspects of a machine or system are not adequately integrated into the design phase, the outcome can be:

- Unnecessary extra cost and other waste, including energy waste
- Machine and system failure, sometimes catastrophic and with loss of life

Powder metallurgical (PM) processes are also significant. Along with the well-known melting / casting / forming process it is also possible to form components starting with powders. Basically, this means that materials in the form of fine powders are compacted and then sintered (processed at a very high temperature but below the melting point of the main constituent) to form an engineering component. The advantages, and consequent real added value, can be very great:

- The components so produced – especially those of complex geometry – are close to the required shape and demand little by way of the energy-consuming drilling, cutting and grinding stages
- There is consequently very high effective use (i.e. low wastage in scrap form) of the input materials – up to 95%

Nonetheless, optimum industrial delivery of these advantages can often be derived from subsequent heat treatment and surface engineering processes, especially where component strength and wear characteristics are concerned. While not widely understood outside metallurgical circles, the PM production route is of very great importance, prime examples of the applications significance of the PM processes being the automotive and aerospace industries.

Nanotechnology: Recent developments in nano-scale science and technology have great significance for surface engineering. It is an interdisciplinary subject requiring expert input from:

- Materials science and engineering
- Mechanical engineering and industrial process technology
- Physics and mathematics
- Chemistry

Industrial success in developing surfaces in which nano-scale materials exert a macro-scale influence on component design and function will contribute to

- Coherent use of materials and the use of inherently 'cheap' substrates to produce high-performance components

- Development of environmentally benign production processes

Nanotechnology, along with its opportunities and science and technology challenges, also represents an area in which careful attention will need to be paid right from the start to the health and safety aspects of processes.

Modelling and simulation

The attractions, economic and otherwise, of descriptive and predictive modelling, as well as of partial and complete simulation of processes, are self-evident. Equally obviously, the rapid development of computer software and systems has enabled important progress in the quantity and quality of mathematical modelling, and the basic mathematical models for thermal processing simulation gradually introduced to date have yielded enormous advantages for some engineering applications. Continued research in this direction attracts increasing attention now that the cutting-edge potential of future developments is evident. Increasingly profound investigations are now in train globally. The number of important research papers in the field has risen sharply over the last three decades. Even so, the existing models are regarded as highly simplified by comparison with real commercial thermal processes. This has meant that the application of computer simulation has thus far been relatively limited precisely because of these simplifying assumptions, and their consequent limited computational accuracy. Excellent results have been obtained thus far with relatively simple shapes for analysis of quenching, carburizing, induction heat treating and other processes. However, before these simulation methods can be applied to many complex shapes and heat treat process, a database of high-temperature material properties must be available. In addition, reliable heat transfer coefficients and must be generated and boundary conditions identified. Extensive and continuing research is still needed, as is collaboration on databases.