EVALUATION OF MECHANICAL PROPERTIES AND MECHANISMS OF DEFORMATION AND FRACTURE

S. Tarafder
National Metallurgical Laboratory, Jamshedpur 831 007
e-mail: star@nmlindia.org

INTRODUCTION

Determination of mechanical properties, together with metallographic examination of microstructures, is the basis for evaluating the quality of metallic materials and their suitability for application, particularly for engineering purposes. To the engineer, mechanical properties are important for selection of materials and for the design of components and structures made from them. Mechanical properties determine the "range" of usefulness of a material, and establish the "service" that can be expected from it.

The term mechanical properties refer to the response of material systems to mechanical actions, primarily the application of loads. The application of load, or a variety of it such as stress, pressure, torque etc., invariably results in deformation, often observed as manifestation of displacement or strain, as elastic and plastic shape change. In its essence, evaluation of mechanical properties entails quantification of the deformation on the application of load or vice versa. The property may sometimes be expressed as an energy obtained from the load-deformation response, or as a parameter that is a function of the loading or deformation characteristics.

The common mechanical properties that are evaluated for metallic materials are :

(i) Hardness, which quantifies the resistance of materials to indentation. A number of hardness testing techniques, using a variety of indentors and employing various scales of measurement are available.

(ii) Tensile properties, which include the strength properties of yield strength (YS) and ultimate tensile strength (UTS), and ductility properties comprising elongation (%El) and reduction in area (%RA), expressed as percentages conventionally. Tensile properties are obtained through tensile tests, from the continuous record of which deformation parameters such as the strain hardening exponent (SHE), the fracture stress and fracture strain can be obtained.

(iii) Compressive properties, which for metallic materials are often taken to be equivalent to the tensile properties, although in many cases subtle difference exists. Compressive properties are obtained through the compression test, and for certain cases of engineering structural materials such as cast irons, are important for engineering design.

(iv) Impact properties, obtained through the impact test, wherein the resistance of a material specimen to impact loading is quantified by the energy absorbed in deforming and fracture of the specimen.

It may be emphasized that the determination of the above common mechanical properties has to be carried out using procedures laid down in standard test methods, using qualified equipment and permissible techniques in order that the mechanical property values that are obtained are acceptable as a quantifying metrics. The importance of appropriate training of personnel employed for carrying out tests for the evaluation of mechanical properties is emphasized in this regard.

Since deformation is central to the determination of mechanical properties, it is important to understand its origin in a material. The non-permanent elastic deformation that is recoverable upon withdrawal of load is based on the Hookean concept of stretching of atomic bonds, and is well known. The permanent and plastic deformation resulting from the application of load is governed by the microstructure of the material. Substructural processes within microstructures at the level of dislocations, at microstructural interfaces like grain boundaries, at second phase particles and precipitates, are responsible for the development of plastic strains. It is instructive to obtain an understanding of the underlying mechanisms in order to develop a fuller appreciation of mechanical properties that evolve through their operation.

Continued deformation of materials leads to their fracture. Fracture can thus be thought of as a consequence of continuation of the processes that result in deformation. As a matter of fact,

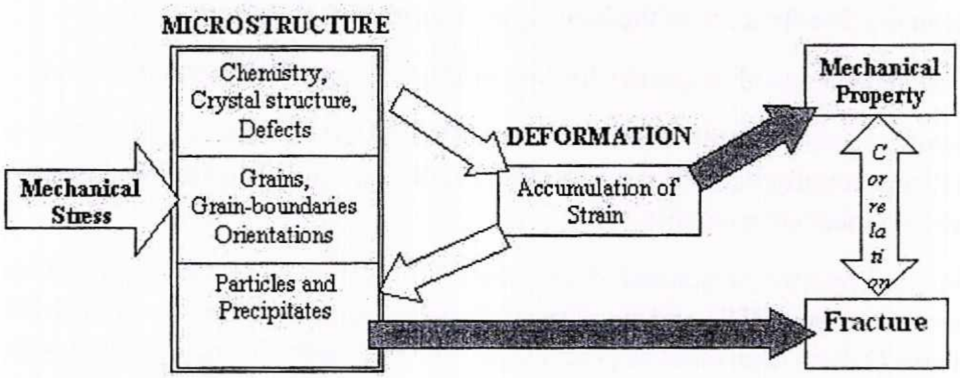

Fig. 1 : Schematic of interactions that are responsible for deformation and fracture

fracture is the result of localized interactions of deformation stresses and strains with microstructural constituents, particularly second phase particles and precipitates. A correlation between fracture and mechanical properties originating from homogenous deformations of the microstructure can therefore be construed. The schematic in Fig. 1 illustrates this correlation.

In modern concepts of designing with materials, the property quantifying fracture resistance is employed extensively, since failure of an engineering structure is often synonymous with fracture. On the basis of the correlation depicted in Figure 1, fracture resistance can be considered as an advanced mechanical property since it is also a response to mechanical action. Fracture resistance is quantified as fracture toughness, and a number of standardized test techniques are available for its determination. Protocols are available for its application in design and in the determination of integrity of engineering structures and components.

Two other phenomena that are responsible for damage and failure of engineering structures are fatigue and creep. Both of these are the result of mechanical action on materials and therefore can be considered to fall in the ambit of mechanical properties, albeit of an advanced variety. The peculiarity of these two phenomena is that they occur under the application of relatively low levels of mechanical loads that under normal circumstances would not lead to deformation and fracture. The damage incorporated through the mechanisms operative in these two cases occur through prolonged application of loads, in a cyclic or repetitive fashion in fatigue and over a long period of time at somewhat elevated temperatures in the case of creep. These are thus special cases in respect of engineering applications, but extremely potent mechanisms of failure nevertheless. It is worthy to develop understanding of these phenomena from the point of view of microstructural and substructural processes operative and also the methods of quantifying the resistance of materials to the processes.