CHAPTER - 3
DEFORMATION AND HARDNESS OF CRYSTALS
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Hardness of a material may be broadly defined as its ability to resist penetration by another particular material. Thus it is a relative property of a material which depends on the elastic and plastic properties of both the penetrated body and the penetrator. In addition to this, hardness of a material depends strongly upon the method of measurement which usually combines in itself various material properties, namely elastic modulus, yield stress (which is a measure of plastic behaviour or permanent distortion), physical imperfection, impurities and workhardening capacity. Imperfections created by thermal or mechanical stresses at the time of crystal growth or after it, bear their effect on microscopic properties like electrical resistivity and on macroscopic properties like mechanical strength and in understanding the fracture mechanics, particularly in ductile metals and alloys etc. In the case of solid solution alloys, to accommodate substitute atoms of greater or smaller size, a change in average interatomic spacing may take place and the solvent lattice may suffer elastic distortion. The distorted lattice causes increased frictional stress to the free movement of dislocations when the alloy is sheared. This means an increase in general hardness.

Deformation in single crystals take place by slip, twinning, crack and fracture. Though the plastic deformation is said to be the permanent deformation in a body or a single crystal, it is defined as the deformation involving creation or motion of dislocations. The phenomena of crack and fracture are classified as ductile or brittle according to the nature of their nucleation and propagation during the deformation. The other deformation phenomena involve lattice reorientation as in deformation twinning and the
occurrence of irregular inhomogeneous deformation like in irrational twins, kink bands, deformation bands, Brilliantov-Obreimov bands etc. Crocker et al\textsuperscript{(1)} have shown that kinking and slip phenomena can also be considered as distinct deformation mechanisms. Both of these phenomena have been studied and reported for zinc by Hess et al\textsuperscript{(2)} and in nickel by Flewitt\textsuperscript{(3)}. The factors affecting the occurrence and nature of deformation produced by different mechanisms are crystal structure, nature of atomic bonds, strain rate, temperature, impurities, method of deformation and crystallographic orientation of the deforming stress axis with respect to the crystal. These will be discussed in detail in chapter 9. The general aspects of deformation by slip and twinning have been treated by various authors (Van Bueren, Cottrell, Reed-Hill, Barrett and Reed-Hill et al)\textsuperscript{(4-8)}. The basic theories of crack and fracture have been reviewed by Lawn et al\textsuperscript{(9)} and Taplin\textsuperscript{(10)}.

**Hardness:**

Many definitions have been given for hardness from time to time but none has been found proper with enough quantitative interpretation and understanding for the aim and theme. Tuckerman\textsuperscript{(11)} explained hardness as a hazily conceived aggregate or conglomeration of properties of a material more or less related to each other. Ashby\textsuperscript{(12)} defined hardness as a measure of resistance to permanent deformation or damage. The general definition of indentation hardness which is related to the various forms of the indenters, is the ratio of load applied to the surface area of the indentation. Meyer\textsuperscript{(13)} proposed that hardness should be defined as the ratio of load to the projected area of the indentation. Hence the hardness has the dimensions of stress. Thus the hardness of a solid is defined in general as resistance to deformation. The deformation in turn is a function of interatomic forces (Tertsch)\textsuperscript{(14)}.
Chatterjee\textsuperscript{(15)} further defined indentation hardness as the work done per unit volume of the indentation in a static indentation test for a definite angle of indenter. On the basis of this definition and Meyer's law, $P = ad^n$, for spherical indenters, he derived a formula for measurement of hardness. Plendl et al\textsuperscript{(16)} defined hardness as the pressure or force per square centimeter which can be conceived as an energy per unit volume and it is in short, the ratio of the input energy and volume of indentation. They further concluded that the resistance itself is a function of the lattice energy per unit volume which is called volumetric lattice energy (U/V), having dimension ergs/c.c. Here "U" is the total cohesive energy of the lattice per mole and "V" is the molecular volume defined as M/S where "M" is the molecular weight and "S" is the specific heat. Thus hardness was considered to be the absolute overall hardness. Matkin et al\textsuperscript{(17)} suggested a correlation of hardness with the dislocation theory. They gave a definition of hardness on the basis of generation and movement of dislocations associated with indentation. Later, Westbrook et al\textsuperscript{(18)} concluded that hardness is not a single property but it is rather a whole complex of mechanical properties and at the same time a measure of the intrinsic bonding of the material. Gilman\textsuperscript{(19)} defined hardness as the strength determining parameter which gives information regarding elastic, anelastic, plastic, viscous and fracture properties of both the isotropic and anisotropic solids.

From all these definitions, the basic qualitative meaning of hardness turns out to be a measure of resistance to plastic deformation. Practically, it carries different meanings to different people; for a metallurgist it is resistance to penetration, for a lubrication engineer it is resistance to wear, for a minerologist it is resistance to scratching, etc. The hardness of materials can be determined by various methods:
1. Scratch method
2. Abrasive method
3. Plowing method
4. Rebound method
5. Damping method
6. Erosion method and
7. Static indentation method

These methods are briefly out-lined below:

1. **Scratch method**:

   This method first developed by Friedrich-Mohs in 1822, is still in wide use today by minerologists. In this method, the ability of one material to scratch another is termed as the hardness of that material with respect to the other. The Mohs method is not suitable for general use with materials of hardness greater than 4. Modifications of this method were later made into other sensitive methods and experiments.

2. **Abrasive method**:

   In this method, the measure of resistance to mechanical wear is taken to be the amount of material removed from the surface under specific condition, where a specimen is loaded against a rotating disc. The rate of wear is taken as the hardness measure.

3. **Plowing method**:

   In this method, a blunt element such as diamond is moved across a surface under controlled conditions of load and geometry and the width of the groove produced is taken as the measure of hardness.
4. **Rebound method**:

In this method, an object like steel ball having standard mass and dimension, is bounced from the surface and the height of rebound is taken as a measure of hardness.

5. **Damping method**:

In this method, the change in amplitude of a pendulum having a hard pivot resting on the surface of the material is taken as a measure of hardness.

6. **Erosion method**:

Here, sand or abrasive grain is caused to impinge upon the surface under standard conditions and loss of material in a given time is taken as a measure of hardness.

7. **Static indentation method**:

In this method, a steel ball, a pyramid or a cone is forced into a surface and the load per unit area of the permanent impression formed is taken as a measure of hardness. The Brinell, Vickers, Rockwell and Knoop tests are of this type.

The most popular and simplest method of hardness measurement is the static indentation hardness method. A hard indenter like diamond, sapphire, quartz, steel etc. having specific geometry is applied slowly under load into the surface to be examined and after a certain time of application, it is carefully removed from the surface. This results into a permanent indentation mark on the surface. The ratio of applied load to...
the area of the mark is termed as the hardness of the specimen indented. In this case, the hardness value depends on the geometry of the indenter. If the specimen is anisotropic, the ridging and sinking of material around the mark produce complicated effects especially with pyramidal indenters (O’Neill)(20) and it requires correction in the formula used to calculate hardness. To accommodate various shapes, sizes and hardnesses of the specimens, a combination of indenter, load, loading procedure and means of indentation measurement is used. The most commonly used indenters are described in Table-1. Diamond indenters are always used for hard materials in order to minimize errors due to elastic distortion of the indenter. In the case of ball indenters, the hardness number will be independent of load only if the ratio of load to indenter diameter is held constant. For cone and pyramidal indenters, hardness number will be independent of load for all loads above a certain minimum value depending upon specimen material. Knoop indenter with rhomb-based pyramid is used to study the hardness anisotropy of a crystal and to eliminate anisotropy effect, pentagonal indenter is used (Brookes et al)(21). The description of various indenters shows that the method of indentation can easily be applied to all kinds of crystalline materials under their own suitable conditions of temperature and environment.

The measurement of hardness of single crystals as well as polycrystals is very essential from the academic, engineering and industrial view points. Though the static indentation method is very simple, it results in a complex development of the stress fields especially in the crystalline materials. Mott(22) and Gilman et al(23) have shown that the indentation hardness value depends on the crystal structure, nature of bonding and elastic modulus of the crystal and it can be used to determine plastic resistivity against the dislocation motion. It has also been observed that
### TABLE - I

<table>
<thead>
<tr>
<th>Material of which indenter is made</th>
<th>Brinell</th>
<th>Rockwell</th>
<th>Vickers</th>
<th>Knoop</th>
<th>Brookes &amp; Moxley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardened steel or tungsten carbide</td>
<td>Diamond</td>
<td>Hardened steel</td>
<td>Diamond</td>
<td>Diamond</td>
<td>Diamond</td>
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<thead>
<tr>
<th>Shape of indenter</th>
<th>Brinell</th>
<th>Rockwell</th>
<th>Vickers</th>
<th>Knoop</th>
<th>Brookes &amp; Moxley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere</td>
<td>Cone</td>
<td>Sphere</td>
<td>Square based</td>
<td>Rhomb based</td>
<td>Pentagonal</td>
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</table>

<table>
<thead>
<tr>
<th>Dimensions of indenter</th>
<th>Brinell</th>
<th>Rockwell</th>
<th>Vickers</th>
<th>Knoop</th>
<th>Brookes &amp; Moxley</th>
</tr>
</thead>
<tbody>
<tr>
<td>D = 10MM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>θ = 120°</td>
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<td>1/16 in.</td>
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<td>1/8 in.</td>
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<td>1/4 in.</td>
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<tr>
<td>1/2 in.</td>
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<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Brinell</th>
<th>Rockwell</th>
<th>Vickers</th>
<th>Knoop</th>
<th>Brookes &amp; Moxley</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Geometrically similar impressions are not obtained</td>
<td>Prepare the surface upon which the further penetration due to major load is based</td>
<td>Geometrically similar impressions are obtained</td>
<td>Hardness of uppermost surface layers can be found</td>
<td>Eliminates the anisotropy normally observed in hardness with all other indenters.</td>
<td></td>
</tr>
<tr>
<td>2. Hardness is read directly on the dial gauge</td>
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<td></td>
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<tr>
<td>3. Hardness value may be appreciable in error due to large amount of recovery along depth</td>
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</tr>
</tbody>
</table>

**Figure**: Geometrically similar impressions are obtained in Brinell testing. Zero azimuth angles are given for each indenter type.
the fundamental mechanism of deformation due to indentation tests, can be either slip or twin or at times fracture.

(i) The most common mode of plastic deformation is slip. It is characterized by the displacement of one part of crystal relative to another along certain definite crystallographic planes and directions. The slip planes are usually of low indices and the slip directions are those of close packing.

(ii) Deformation in some crystals takes place by twinning. Here one part of a crystal may change the lattice orientation with respect to another in a definite symmetrical way. Twinning was described by Schmidt et al\(^{(24)}\) as the simple sliding of one plane of atoms over another plane and concluded that the movement of each plane is proportional to its distance from the twinning plane. Partridge\(^{(25)}\) in his study of the microhardness anisotropy of zinc and magnesium single crystals observed deformation twins and finally concluded that the resolved shear stress criterion is insufficient to account for the observed distribution of twins and any analysis which attempts to relate deformation twinning with hardness anisotropy must take into account the dimensional changes which occur during twin deformation. The slip and twinning of diamond was reported by Phaal\(^{(26)}\) with diamond indenter indenting on the flat and smooth surface of diamond. Vahldick\(^{(27)}\) reported similar results in the case of molybdenum carbide single crystals using Knoop and Vickers indenters. Interferometric studies of the indented surfaces have brought revolution in the understanding of nature of deformation and the history of the sample under test. The Vickers indented surfaces of steel, tin and bismuth were thus studied by Tolansky et al\(^{(28)}\) who observed maximum distortion along the medians bisecting sides of
the square and minimum along the diagonals. They finally concluded that the symmetry in the fringe pattern is purely crystallographic and it has nothing to do with the orientation of the square of the indentation mark. They further concluded that the convex sides corresponding to extended wings in the interference pattern were "piled-up" regions and the concave sides were "sinked-in" regions.

On the basis of correlation between hardness anisotropy and slip behaviour of single crystals, Hannink et al.\(^{(29)}\) studied and reported the slip behaviour and slip system in cubic carbides by the method of hardness anisotropy measurements. Boyarskaya et al.\(^{(30)}\) reported the shape of the indentation mark depending on the orientation of the indenter with respect to the indented surface in cubic crystals. Mokievskii\(^{(31)}\) reported the non-square shape of the indentation mark related to the anisotropy of elastic properties of the crystals whereas Boyarskaya et al.\(^{(32)}\) related the non-square shape to the anisotropy of plastic properties of the crystals. In the case of aluminium single crystals, Petty\(^{(33)}\) attributed the variation in hardness value for different orientations to the pressure resolved in the surface. Shimotori\(^{(34)}\) has given a mathematical expression for Knoop hardness anisotropy of cubic crystals. Brookes et al.\(^{(35)}\) have reported the effect of plastic anisotropy by establishing a correlation between the effective resolved shear stress and the hardness values obtained.

Tabor\(^{(36)}\) derived an expression, viz, \(H = CY\) for hardness during indentation experiments on the basis of hydrostatic pressure developed below the indenter. The expression shows the relation between the mean contact pressure developed or hardness, \(H\), and uniaxial flow stress, \(Y\), of the material, where \(C\) is the proportionality constant having value nearly equal to 3 which is known as constraint factor depending on the
geometry of the indenter and deformation behaviour of the material. Hertz\(^{(37)}\) and Shaw et al\(^{(38,39)}\) using elastic theories, reported the value of the constraint factor \(C\) to be 2.8. Hill\(^{(40)}\) and Shield\(^{(41)}\) used the slip-line field theories and evaluated the constraint factor \(C\) to be 2.54 and 2.82 respectively, on the basis of the assumption of a rigid-plastic material. The above theoretical values agree well with the observed value of about 3. Abson et al\(^{(42)}\) worked on aluminium, steel and Armco iron and reported the values of constraint factor \(C\) quite higher, in a range upto 10. Such large differences were explained to be due to the difference in work-hardening rates during indentations on annealed and worked specimens. The effect of included angles of conical and pyramidal indenters on the constraint factor \(C\) has been studied by Dugdale\(^{(43-45)}\). Gilman et al\(^{(23)}\) reported the correlation of indentation hardness with the elastic modulus using collected data for various materials and further noted the elastic modulus as an important factor to determine plastic resistivity with respect to dislocation motion. Gilman\(^{(19)}\) has already given the graphical correlations of the other physical properties which are fundamental in nature and play an important role in determining the hardness. Apart from flow stress, these physical properties are, elastic modulus for metals and covalent crystals, interatomic distances for covalent crystals, average band gap, energy-gap density, optical energy gap and homopolar energy gap.

During deformation, the dislocations are multiplied by one or several mechanisms which result in decreasing the spacing and interactions between them and increasing their density. As a result, the dislocation mobility decreases giving rise to work hardening. The strength of dislocation interference depends on the nature of the crystalline material and on the ratio of temperature of deformation to the melting...
Important factors which can increase resistance to dislocation motion are as under:

1. Work hardening,
2. Impurity hardening, where the impurities tend to segregate to dislocations,
3. Decreasing grain size in polycrystals where the grain boundaries are barriers to dislocation motion,
4. Dispersion of second phase fine particles in crystals and
5. Phase transformation by quenching.

Gilman\(^{(19)}\) studied CdS crystals and reported the local pressure created below the indenter to be responsible for the change in phase of the crystal and thus finally affecting the measured value of hardness. Boyarskaya et al\(^{(46)}\) reported that the materials with high dislocation mobility are harder than those with low dislocation mobility. But they further reported that though the semimetals have small microhardness, the latter has been found to be associated with low dislocation mobility. Apart from this, Gilman\(^{(19)}\) observed impurity hardening and phase transformation by indentation in some cases.

From the above brief description, it can be said that plastic deformation induced in a material by an indenter under load, depends on various factors in a complicated way defying simple analysis.

**Variation of hardness with load:**

From the geometrical similar shapes of the indentation marks for various loads, it can be shown that the hardness is independent of load though it is not true experimentally for certain ranges of applied load.
The hardness obtained by the indentation test is not the actual hardness prior to indentation. This is so because the indentation process deforms the indented region of the sample. This deformation has to bear its effect in responding to the progressive penetration of the indentation. Usually at low applied loads, the deformation causes work hardening of the surface layers. Hence the measured hardness is more than the actual. Thus the factors affecting the hardness of a material go on changing with applied load. The main findings in this respect are briefly given below:

Knoop\(^{(47)}\) and Bernhardt\(^{(48)}\) observed increase in hardness with decrease in load. Campbell et al\(^{(49)}\) and Mott et al\(^{(50)}\) observed decrease in hardness with decrease in load. Taylor\(^{(51)}\) and Bergsman\(^{(52)}\) observed no significant change in hardness by varying load. A relationship between microhardness and applied load has been given by Meyer\(^{(13)}\) as $P = ad^n$, where $P$ is applied load, $d$ is the diagonal of the indentation mark, $a$ & $n$ are the constants of the material under test.

In the case of Vickers microhardness, theoretically the value of the exponent $n$ is equal to 2 for all indenters that give geometrically similar indentation marks. It implies a constant hardness value for all loads. Hanemann\(^{(53)}\) concluded from his observations that in the low load region, $n$ has a value less than 2. Onitsch\(^{(54)}\) found a value of $n$ between 1 and 2. Grodzinski\(^{(55)}\) found variation of $n$ from 1.3 to 4.9. However, most of the values of $n$ were found to be 1.8. Thus the standard hardness values obtained were expected to yield constant results but the actual results obtained by different workers revealed disparities amounting to 30-50%. Due to this variation in the results, a high load region has to be selected which leads to the definition of a load independent region of microhardness. The microhardness values so obtained for this region again show scattered results even though the
The term microhardness refers in principle to microindentation hardness, as it actually refers to the hardness measurement on the microscopic scale. Some workers prefer the term 'low load hardness'. However, the ranges of macro and microindentations are not practically defineable. But three possible regions can be crudely defined as follows:

(1) Microhardness : From the lowest possible loads upto maximum of 200 gms.

(2) Low load hardness : Loads from 200 gms to 3kg. The most characteristic region comprises of loads from 200 gms to 1kg.

(3) Standard hardness : Loads over 3 kg.

In the work reported by many workers from 1960 onwards, the hardness has been found to be increasing at low loads, then remaining constant for a range of higher loads.
In spite of all these, the hardness indentation has been very fruitfully used to study plastic deformation. For example, Murphy\(^{56}\) studied hardness anisotropy in copper crystals and the anisotropic variation in hardness and hence the plastic deformation has been shown to be partly due to escape of primary edge dislocations. Sugita\(^{67}\) has studied the indentation hardness of Ge crystal and found occurrence of ring cracks and radial cracks and that the load required to produce the observable cracks increased with the temperature. The temperature at which the microscopic slip lines become observable was higher in heavily doped crystals than in high purity crystals, indicating that dislocation multiplication was strongly affected by impurities. Kosarich et al\(^{58}\) studied the formation of twins produced in Bi, Sb, Bi-Sb, Bi-Sn and Bi-Pb single crystals under the action of concentrated load by diamond pyramid microhardness tester. They showed that the length \(l\) of twins was proportional to the diagonal \(d\) of the indentation and the intensity of twinning is given by the coefficient \(\alpha\) in the equation, \(l = a + \alpha d\), where "\(a\)" is a constant. The value of \(\alpha\) was more for homogeneous alloys and increased with Sb content and remained constant for higher concentration of Sn and Pb. The variation of hardness with load was also studied by Shah et al\(^{59}\) who explained hardness in terms of slip taking place due to deformation in the tellurium crystals. Edelman\(^{60}\) found that the microhardness of InSb and GaSb single crystals decreased exponentially with temperature. The presence of deflection on the curves at 0.45 - 0.50 \(T_m\) indicates deformation by slip. The activation energy for plastic flow in InSb and GaSb was estimated to be 0.6 eV. Dyer\(^{61}\) using slip-line and etch pit observations, on copper, studied possible dislocation interactions in fcc crystals and their effect on the deformation process. Sestak et al\(^{62}\) provided an account of the complex nature of slip in bcc metals by performing indentations in Si-Fe alloys.
Hardness variation was also studied with respect to the impurity content, dislocation density and the change in mobility of dislocation by various workers. Milvidski et al\(^{(63)}\) observed decrease in hardness with increase in concentration of impurity and dislocation density in silicon single crystals. Kuz'menko et al\(^{(64)}\) observed decrease in hardness due to change in mobility of dislocations as a result of excitation of electrons during lighting and their transition to higher energetic zone in titanium iodide and termed this a "photochemical effect". Beilin et al\(^{(65)}\) observed decrease in the hardness upto 60% illumination in Ge and Bi. The decrease in hardness was attributed to the induced photoconductivity, which altered the widths of the dislocation cores at the sample surface and in turn altered the plasticity.

The effect of impurity on hardness was also studied by various workers. Dryden et al\(^{(66)}\) studied the hardness of alkali halides when low concentrations of divalent cations were incorporated in the crystal lattice on the basis of dielectric measurement of doped alkali halide crystals. The State of aggregation of the divalent impurities was found to bear its effect on the critical resolved shear stress. Recently, many workers have studied the Vickers microhardness of Cd\(_x\)Hg\(_{1-x}\)Te alloys at room temperature as a function of composition \(x\) and their findings are as follows:

(i) Barbot et al\(^{(67)}\) reported that the hardness increases as a function of composition upto \(x=0.75\)

(ii) Fissel et al\(^{(68)}\) reported the increase in hardness with increase in \(x\) from 220 MPa at \(x=0\) to 440 MPa at \(x=1\), exhibiting a maximum of about 850 MPa at \(x=0.75\). Here, the hardening rate, \(dH/dx\), was observed to be strongly dependent on the composition but the solid...
solution hardening was observed due to elastic interactions of solute atoms with gliding dislocations and ordering effects.

(iii) Andrews et al\(^{(69)}\) reported the same results of an increase in the hardness in the composition range \(0.6 < x < 0.8\) for \(\text{Hg}_{1-x}\text{Cd}_x\text{Te}\) alloys. Their detailed study was for four II-VI semiconducting alloy systems: \(\text{Hg}_{1-x}\text{Zn}_x\text{Te}\), \(\text{Hg}_{1-x}\text{Cd}_x\text{Se}\), and \(\text{Hg}_{1-x}\text{Zn}_x\text{Se}\). They further reported that, the substitution of Zn for Cd in the Te-based system, results in an increase in the microhardness which supports theoretical predictions that Zn additions stabilize the weak Hg–Te bond and enhance resistance to plastic deformation. Again, a maximum in the microhardness occurs in the composition range \(0.6 < x < 0.8\) and similar solid solution hardening behaviour was observed in the \(\text{Hg}_{1-x}\text{Cd}_x\text{Se}\) system as in the case of \(\text{Hg}_{1-x}\text{Cd}_x\text{Te}\). Also, hardening rate \(\text{d}H/\text{d}x\) in the Se-based system was observed higher than in the Te-based system.

Samsonov et al\(^{(70)}\) have studied temperature dependence of microhardness of titanium carbide in the homogeneity range and reported that hardness decreases with decrease in carbon content. Acharya\(^{(71)}\) reported that the hardness of Zn and KBr decreases with the quenching temperature while the hardness of TGS increases with the quenching temperature. Thus the hardness of a material depends on applied load, impurity, composition, crystal orientation and general mechanical state of the crystal. Over and above, the time dependence of plastic deformation (i.e. creep) plays a prominent role in hardness measurements. The time dependent behaviour has been found in many cases to be closely parallel to the creep characteristics of the material in unidirectional stress tests. These characteristics are intimately associated with temperature. At the same time the nature and amount of plastic deformation and the measured hardness itself depend on the temperature. Recently in 1992,
Fujiwara et al\textsuperscript{(72)} have studied the indentation creep deformation by pencil glide in tin crystals. The investigation was on the deformation mechanism of [001] pencil glide in the crystals at the temperatures of 298, 333 and 373 K using a Vickers microhardness tester and the nature of the pencil glide tensile tests at various strain rates in the same temperature range. They reported that the size of the impression produced increased with increasing load and temperature. It was concluded that the steady state deformation due to the pencil glide was rate-controlled probably by cross slip between planes containing the [001] slip vector. Many workers have analysed the creep characteristics. However, most significantly, Atkins et al\textsuperscript{(73)} on the basis of kinematic analysis have given a successful hardness-time relation in terms of temperature and creep activation energy.

The time-dependence of microhardness was studied in this laboratory on different single crystals by various workers (Acharya C.T., Shah R.T., Desai C.F., Shah A.J. and Shah R.C.)\textsuperscript{(71,74-77)}.

A detailed account of the work carried out by the present author, on deformation and microhardness of InBi:Te single crystals, is given in chapters 9 and 8.
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