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INFLUENCE OF INTERSTITIALS ON THE MECHANICAL PROPERTIES OF GROUP IVb METALS(*)

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This review is concerned with the role of interstitials hydrogen, oxygen, nitrogen and carbon in the mechanical behaviour of titanium, zirconium and hafnium. This is of recurrent interest as these metals form rather extensive solid-solutions with most of the interstitials, which in turn alter the mechanical properties of the alloys significantly.

For studying the distortion introduced in the hcp lattice by the addition of interstitials, it is necessary to consider the geometry of voids present in the lattice. The octahedral void, though non-symmetric because of the less than ideal axial ratio, is sufficiently big to accommodate oxygen, nitrogen and carbon, while hydrogen is taken into the tetrahedral hole. This choice of voids results in nitrogen, oxygen and carbon raising the α-β transition temperature and hydrogen lowering it. From lattice parameter measurements, it is seen that for nitrogen and oxygen both a and c parameters increase in such a way that $\frac{c}{a}$ remains almost constant. In carbon, on the other hand, c increases more than a, increasing c/a ratio towards the ideal value. Further, the lattice distortion introduced by one atom of interstitial is maximum for carbon followed by nitrogen and oxygen. The solubility is inversely proportional to this distortion. Hydrogen is again an exception to this rule, it is practically insoluble in the α-phase though the distortion introduced by hydrogen in the lattice is minimum.

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The mechanical properties of IVb metals are profoundly influenced by the amount of interstitials they contain. The increase in strength by the interstitials is so much in these metals that ductile-brittle transition could take place at room temperature in zirconium - 5 at % oxygen alloy. To account for this increase in strength, tensile test experiments have been carried out at various temperatures and they conclusively show that the increase in strength is largely due to the thermal component of the flow stress. This is to be expected if interstitials pin the dislocations producing short-range hardening. From an analysis of various short-range hardening models, it could be seen that Fleischer's theory of solution - hardening satisfactorily accounts for the experimental results obtained in zirconium-oxygen/carbon, titanium-oxygen and hafnium/oxygen systems. In addition to the increase of the thermal component, there is also an increase of the long-range flow stress. Various possible hardening mechanisms could contribute to this, including strain-ageing.

Hydrogen contributes to the change in strength only through its presence as second-phase hydrides. They could be present either as big needle-shaped platelets or as small quenched-in loops. The big precipitates decrease the strength as they provide easy sites for nucleation of microcracks leading to eventual failure of the matrix. On the other hand, the small quenched-in loops, increase the strength acting as non-deformable hard particles. In addition to these two types, mention must also be made of the stress-orientation of hydrides, by the application of tensile or compressive stress during precipitation. These hydrides, because of the strong orientation effect increase or decrease the strength radically, depending on whether hydrides are along or normal to the tensile stress axis.

Though the octahedral voids are near symmetric, the interstitials occupying them still tend to give stress-induced internal friction peaks as could be seen from the experimental results obtained in titanium-oxygen and hafnium-oxygen systems. Explanations to account for this behaviour have been advanced on the basis of impurities occupying substitutional sites thus

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altering the bonding and the identity between holes. Internal-friction results obtained in hydrogen alloys are anomolus which in part may be due to the size, morphology, and crystal structure of the hydrides. Carefully controlled experiments are needed in this system.

All the interstitials barring carbon, tend to make the matrix brittle. While nitrogen and oxygen cause brittleness even when in solution in the matrix, hydrogen causes failure when present as hydrides. Experiments in zirconium-oxygen system have shown that brittle-fracture encountered may be due to increased strength of zirconium-oxygen bonding. This almost non-metallic bonding could cause failure by suppressing plastic deformation. Failures due to hydrides have been accounted on the basis of decohesion between the matrix and the precipitates introduced due to the blocking of dislocations or twins.

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