ABSTRACT

Chapter one introduces the importance of boriding as an effective case hardening technique.

Chapter two presents a literature survey of boriding methods (pack boriding, molten salt boriding, fused salt boriding, electrolytic boriding, gaseous boriding and special boriding techniques like plasma boriding and laser boriding). Additionally it surveys the literature on morphology, microstructure, mechanical and chemical properties of the borided specimens.

Chapter three deals with the scope of the present investigation and its objectives. One of the major objective was to develop innovative and economical processes using easily available and low cost materials, resulting in superior microstructure and improved mechanical properties comparable to the best international processes such as B_4C based processes. In these processes optimisation of composition, temperature and other process variables to improve the structure and properties was another objective. Kinetic studies were also carried out and the activation energy was estimated for pack boriding and molten salt boriding processes. Further, an innovative modification, namely "Interrupted boriding" or "Multipass boriding" was attempted in pack boriding and molten salt boriding processes. The microstructure, microhardness and mechanical properties of these specimens were compared with the normal continuously borided specimens.

Microstructural investigations using optical microscope, SEM, Microhardness studies and tension tests to estimate yield strength, ultimate tensile strength, ductility, toughness and wear tests including pin- on- disc test, and falex tests (for scuffing resistance) were carried out.

X ray diffraction studies and EPMA were employed for analysis and characterisation of the boride layers.

Chapter four describes the experimental procedure of the various boriding methods, the chemicals and raw materials and conditions of (i) pack boriding (with B_4C, or with ferroboron). (ii) Molten salt boriding (with B_2O_3 + Al mixture, borax + boric acid mixture containing either B_4C or ferroboron, ferrosilicon magnesium). (iii) Electrolytic boriding using borax + boric acid mixture with additives like NaCl, NaF, Na_2CO_3. Composition optimisation as well as optimisation of other variables for best microstructure and mechanical properties were attempted. For this, optical microscopy, SEM, EPMA, tension test, X-ray diffraction analysis, wear tests (pin on disc test and Falex test) and corrosion tests were carried out. Also kinetic studies were carried out and activation energies for pack and molten salt boriding were estimated. Besides these, a novel modification called interrupted boriding instead of continuous boriding was attempted and properties compared.

Chapter five enumerates the results and discussions of the various experiments carried out.

Chapter six lists the major conclusions and suggestions for future work. The major conclusions are the following :

(i) In pack boriding (a) A mixture containing 5% boron carbide is adequate (and in fact optimal) for a desirable uniform case containing a single phase (Fe_2B) instead of two phases (FeB and Fe_2B), resulting in better wear resistance, strength and toughness. (b) Low cost ferroboron can effectively substitute more expensive boron carbide or amorphous boron, to yield a good quality boride case. (c) Composition optimisation of the ferroboron was achieved. (d) Ammonium chloride activated boron carbide or ferroboron mixtures did not give satisfactory results.

(ii) In molten salt boriding, (a) Use of boric acid (B_2O_3) + Aluminium mixture did not result in a good case. (b) Use of borax + boron carbide (10%) yielded a satisfactory case. (c) Ferroboron (20%) can effectively replace boron carbide to get a satisfactory boride case. (d) Ferro-silicon-magnesium (FeSiMg) can also effectively replace boron carbide or ferroboron in borax based melts. (e) Melt composition was optimised for yielding good case with single phase boride (Fe_2B), good surface finish, easy slag removal and low viscosity. (f) The process was carried out effectively in normal, ambient atmosphere, and there was no need for any special gas atmosphere.

(iii) In electrolytic boriding, (a) The process is established as a speedy and effective one, even in normal ambient atmosphere itself. (b) Out of the three additives attempted to borax-boric acid electrolyte, (namely NaF, NaCl and

Na_2CO_3) only Na_2CO_3 was found to be effective, safe and convenient. (c) Composition, temperature and current density were optimised to get a uniform boride case, with a single phase (Fe_2B) instead of a two phase layer (FeB + Fe_2B).

(iv) In all the above three processes, based on the EPMA results, it is found that silicon is pushed from the surface toward the core resulting in enrichment of silicon below the boride layer.

(v) In kinetic studies conducted on the pack process (using ferroboron) and molten salt process (using borax + boric acid mixture), the incubation period and activation energy were determined. Activation energy value depends on the process and conditions.

(vi) Compared to continuous boriding, interrupted boriding (or multiple pass boriding) produces thicker, more rounded boride arms (or needles), with small globular precipitates between the needles. These result in improved toughness, strength and ductility compared to continuous boriding. This has been observed both in pack boriding and molten salt boriding.