Chapter 6

Conclusions & Suggestions
for future work
CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

6.1 CONCLUSIONS

1. In pack boriding,
(a) A mixture containing 5% boron carbide is adequate (and in fact optimal) for a desirable uniform case, with a single phase (Fe₂B) instead of two phases (FeB and Fe₂B), 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 was achieved to get a good quality case, similar to that obtained with boron carbide (20% ferroboron, 5% KBF₄, 5% Al₂O₃ balance SiC).
(d) Ammonium chloride activated boron carbide or ferroboron mixtures did not give satisfactory results.

2. In molten salt boriding,
(a) Use of boric acid (B₂O₃) + Aluminium mixture did not result in a good case.
(b) Use of borax + boron carbide (10%) yielded a satisfactory case.
(c) Boron carbide (10%) can be effectively replaced by the less expensive ferroboron (25%) to get a satisfactory boride case.
(d) Even low cost foundry grade ferro-silicon-magnesium (FeSiMg) can effectively replace costly boron carbide or amorphous boron in borax based melts, to give a good boride case.
(e) Melt composition was optimised for yielding good case with single phase boride (Fe₂B), good surface finish of the case, easy slag removal from the
specimen, and low viscosity of the melt. The optimal composition has the \( \text{Na}_2\text{O}/\text{B}_2\text{O}_3 \) ratio close to the eutectic point in the \( \text{Na}_2\text{O} - \text{B}_2\text{O}_3 \) system.

(f) The process was carried out effectively in normal, ambient atmosphere, and there was no need for any special (neutral or reducing) gas atmosphere.

3. In electrolytic boriding,

(a) The process is established as a speedy and effective one, even in normal ambient atmosphere itself, just like molten salt boriding.

(b) Out of the three additives attempted to borax-boric acid electrolyte, (namely \( \text{NaF}, \text{NaCl} \) and \( \text{Na}_2\text{CO}_3 \)) only \( \text{Na}_2\text{CO}_3 \) was found to be effective, safe and convenient, at an optimal amount of 27%.

(c) Composition, temperature and current density has been optimised to get a uniform boride case, with a single phase \( (\text{Fe}_2\text{B}) \) instead of a two phase layer \( (\text{FeB} + \text{Fe}_2\text{B}) \).

4. 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.

5. 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. The activation energy value for this molten salt process was less than that of pack process. This indicates that boriding medium does indeed have an effect on activation energy.

6. 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. This modification in the microstructure results in improved toughness, strength and ductility compared to continuous boriding. This was observed both in pack boriding and molten salt boriding.

Some Refinements to Boriding Processes
SUGGESTIONS FOR FUTURE WORK

1. Multicomponent boriding (B-Al, B-Cr, B-Si, B-Ti) may be attempted, for stainless and high alloy steels, to improve their corrosion resistance as well as mechanical properties.

2. Non-ferrous alloys, especially alloys of Ni, Ti and even other non-ferrous alloys after suitable plating, can be treated by boriding, for increased service life.

3. There is considerable controversy about distribution of alloying elements in and outside the boride needles and substrates. These can be investigated in detail.

4. Recovery of boron from waste mixes used for molten salt and fused salt electrolysis processes may be investigated for economic attractiveness and technical feasibility.

5. Interrupted Vs Continuous boriding comparison can be attempted in electrolytic boriding.

6. Laser modification of the borided surface and its effect on the Microstructure and strength properties can be investigated.

7. Cost estimations can be made for actual industrial components and comparisons can be made among the processes.