**Hot Dip Galvanizing rebar – future projections.**

**BACKGROUND**

Although the hot dip galvanizing industry sees its future in construction in the protection of structural steel, one must not forget that, especially in South Africa, concrete structures dominate in buildings. In the UK the movement away from concrete to structural steel has been phenomenal over the past 15 years or so such that structural steel now represents 74% of the new construction market versus 25% in the past. Clearly, should this transition become a reality locally the opportunities for all those involved in this industry, including the hot dip galvanizing industry would be outstanding. However, this article will focus on the opportunities presented by the existing building practices.

Infrastructure structures, which are critical in nature, such as bridges, must be designed with longer life expectancies than in the past. In the UK bridge design lives have to be 120 years+, in the USA in excess of 75 years is mandatory. Is this an opportunity for hot dip galvanizing? Worldwide yes, but what about locally? The total market for reinforcing steel (rebar) in South Africa is of the order of 300 000 tonnes per year. If 5% of this could be converted to HDG (as in Australia) the added consumption of zinc would be 750 tonnes. How can hot dip galvanized rebar assist in the construction industry?

**CORROSION IN CONCRETE**

We all know concrete as a universal building material. Its key advantages are its low cost, lack of flammability and strength in compression. However, the need to have some load bearing strength requires the use of rebar. Concrete is composed of course aggregate (gravel or stone), fine aggregate (sand), cement, water and special additives to modify properties. Typically, 70% is aggregate and 30% paste (water/cement) to fill all pore spaces – the glue. Concrete hardens by hydration, which is why it warms during curing.

Typical cement (ordinary Portland cement, OPC) is made by blending and heating (at 1500°C) lime (as limestone or marble) CaCO₃ and clay or shale containing iron, silica and alumina. This produces a clinker, which is pulverized. Additives include accelerators, retarders, plasticizers, corrosion inhibitors, reinforcing micro-fibres, flyash (to improve strength and workability) and colouring agents.

Under normal conditions, in a non-aggressive environment, OPC protects the steel reinforcing against excessive corrosion providing that the concrete permeability is low and the steel-concrete interface is free of cracks or voids. OPC contains high concentrations of calcium, sodium and potassium oxides. When water is added, these can leach out and form hydroxides, the alkalinity so produced passivating the steel. Thus, the steel rebar is protected from corrosion. However, concrete is permeable to an extent so that there is interaction with the atmosphere and, in aggressive climates, chloride penetration of the concrete can occur. These effects are shown schematically below.
FIGURE 1 – GENERALIZED MECHANISM FOR CORROSION OF STEEL IN CONCRETE

Carbonation is the result of atmospheric CO₂ diffusing into the concrete and neutralising the alkaline elements in the concrete matrix. The process is slow but once the pH approaches 7 the salts become soluble and rusting of the steel will commence in the presence of chlorides. The chloride threshold is usually quoted as 0.6 (Cl⁻ / OH⁻).

Although the diffusion of Cl⁻ ions is said to observe Fick’s 2nd Law of Diffusion, this does not take into account cracks and the normal heterogeneous qualities of concrete which can assist Cl⁻ movement to the rebar. Naturally, the corrosion rate is also dependent upon the availability of water and oxygen at the corrosion site. Unfortunately, the corrosion products of steel are over three times the volume of the original steel and exert great tensile disruptive stress on the surrounding concrete resulting in the spalling we are all familiar with. Measured rates of carbonation and chloride penetration are shown below.

FIGURE 2 – CARBONATION PENETRATION VERSUS TIME
FIGURE 3 – CRITICAL CHLORIDE ION PENETRATION VERSUS TIME

FIGURE 4 – TYPICAL SPALLING ON A STEEL REINFORCED BRIDGE STRUCTURE.

REINFORCING SPECIFICATIONS

In South Africa, SABS 0100:1992 Code or Practice. The Structural use of concrete specifies the requirements for the use of reinforcing. Critical issues relating to reinforcement performance are concrete strength (i.e. water to cement ratio - different concrete strengths are available, generally defined by the water to cement ratio, with <0.6 being typical) and depth of cover. These issues are all dealt with in SABS 0100 including placing regimes, issues relating to the increased cover required in aggressive environments and the quantitative definitions of these, in terms of indices, are covered in the Annexures. Rebar must comply with SABS 920:1985 Steel bars for concrete reinforcement. Plain carbon steel bar and deformed high strength bar are described.
HOT DIP GALVANIZED REBAR

Zinc remains in the passive condition between pH 6.5 and 12.5. The soluble zincate is produced in fresh wet cement paste but as the alkalinity drops slightly, the zincates passivate. Hydrogen is produced during this passivation process but experience shows that a small chromate presence (< 0.002%) limits this reaction. The chromate can be added either to the cement paste or, more typically, normal chromate passivation eliminates any potential problems associated with hydrogen evolution.

Carbonation of concrete is not aggressive to hot dip galvanized rebar as the resultant pH is not aggressive to zinc.

Local trials using HDG and other rebar materials, such as stainless steels, illustrated the advantages of stainless steels. However, as stated above, Cl⁻ ion diffusion is very much dependant upon the homogeneity of the concrete and the type of environment the concrete is exposed to. These studies used a low depth of cover (25mm) which should not be used in practice under the severe conditions of the test.

Studies in the USA (Florida) showed that even in a marine environment the maximum Cl⁻ ion level was 1.4 kg/m² (or 0.7 ppm) after 5 years of testing. Although double the American Concrete Institute threshold level for the initiation of corrosion on uncoated rebar (0.7kg/m²), it appears as if during the initial stages a tenacious passive film is developed on the galvanized surface which can tolerate high chloride levels in the future. Other surveys in marine structures have shown galvanized rebars to have been exposed to Cl⁻ levels as high as 2.2% (by weight) over a period of 10 to 20 years with less than 10% loss of the original coating - and no record of failure. This may well explain the difference between laboratory studies with poor coverage (where accelerated results are needed) and “real life” exposure where HDG rebar offers substantial improvement in performance over uncoated rebar.

Epoxy coated rebar is not a cost effective corrosion protection system for bridge decking. In fact, the Virginia Transport Research Council in January 1997 stated – “For 95% of bridge decks the epoxy coating will debond from the steel before the Cl⁻ ion arrives at the corrosion site and therefore provides no additional service life”.

MECHANICAL ISSUES RELATING TO HDG

Bond strengths in concrete rely heavily upon the amount of deformation of the bar rather than the actual bond between the rebar and the concrete. This is one of the continuous discussions relating to the amount of corrosion that should be allowed on uncoated rebar to effect good bonding. Pull out tests have been carried out in many instances using HDG rebar and the following values are typical:

<table>
<thead>
<tr>
<th>Bond Strength, MPa</th>
<th>Deformed bar</th>
<th>Plain bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black steel</td>
<td>150</td>
<td>3.3-3.6</td>
</tr>
<tr>
<td>Hot Dip galvanized steel</td>
<td>160 (190 passivated)</td>
<td>1.3-4.8</td>
</tr>
</tbody>
</table>
In essence the values are identical. It is often thought that HDG rebar should be pre-bent prior to galvanizing to avoid flaking of the bend area if severely bent on site. Studies show that provided that the uncoated area does not exceed 3 mm cracking after bending will not impede performance. Marine studies have shown that a degree of cathodic protection is afforded to these areas.

**ECONOMICS OF HDG REBAR**

Whilst the use of binders such as Blast Furnace slag assist in improving homogeneity and, therefore, strength and impermeability, the majority of concrete mixes use OPC and therefore, this discussion will focus on ordinary cement.

Life cycle performance evaluation is gradually becoming an important requirement for the design of new concrete structures and for the inspection, repair, upgrading, replacement and demolition decisions of aging concrete structures – does HDG have a role to play?

Whilst the cost of hot dip galvanizing may be up to R2000 per tonne, the cost of galvanized rebar is typically less than 2% of the total building cost. The cost of using HDG rebar can be further reduced if its application is restricted to aggressive areas or critical structural elements (especially in areas where there are constraints on the amount of cover that can be provided). These can include:
- thin pre-cast cladding
- exposed facades and
- exposed beams and columns

A typical analysis would be:

<table>
<thead>
<tr>
<th>Table 1. Cost comparison - HDG vs. black rebar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of structure</td>
</tr>
<tr>
<td>Column</td>
</tr>
<tr>
<td>Slab</td>
</tr>
<tr>
<td>Cost of black rebar/tonne</td>
</tr>
<tr>
<td>Cost of galvanizing/tonne</td>
</tr>
<tr>
<td>Cost of HDG rebar</td>
</tr>
<tr>
<td>Mass of rebar kg/m3</td>
</tr>
<tr>
<td>Materials cost of structure/m3</td>
</tr>
<tr>
<td>Total cost using black steel/m3</td>
</tr>
<tr>
<td>Total cost using HDG steel/m3</td>
</tr>
<tr>
<td>Increase with HDG</td>
</tr>
<tr>
<td>Increase if used for 10% of job</td>
</tr>
</tbody>
</table>

This increase is minor when one considers total life costing.
CASE HISTORIES

1. Project: Gateway Shopping Centre, Umhlanga Kwa Zulu Natal  
   Consultant: Tobell, Stretch and Associates  
   Contractor: Grinaker, Group 5, Wilson Bayley Holmes  
   HDG used in: 340 Tilt-up panels facing the sea  
   20 x 5 x .175 metres each  
   weight 45 tonnes each  
   Total mass of panels 15 300 tonnes  
   Approximate mass of HDG rebar 700 tonnes  
   Reason for decision: Corrosive environment facing the sea.

2.