CORROSION AND WEAR IN MOULDING BOXES

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We assess the potential causes of damage to mould box ends and find that both *HOT corrosion*, due to burning of emitted volatiles, and *COLD corrosion*, due to the presence of high humidity (and possibly high chloride ion concentration), are likely to contribute to the damage. We suggest strategies to minimise the damage, including venting of the volatiles, ventilation of the pallet grooves during cooling and minimisation of brushing effects during cleaning. Some calculations are described in an attempt to quantify the various effects discussed, but we are unable to accurately estimate their significance.

1. Introduction

Toowoomba Foundry makes a range of cast iron metal products including brake drums, wheel spiders and pump housings. These are cast in large sand-filled moulds. The mould boxes are made of metal and consist of separate top (cope) and bottom (drag) parts, which sit on a pallet car that travels around the mould line (see Figure 1). The top surface of the pallet car is ribbed, to allow gaps between the bottom of the mould box and the car. The gaps provide vents for steam volatiles and water to escape during the casting process. A mould is filled with a mixture of damp sand, coal dust and binder, which is impacted into the mould by compressed air. Blanks are placed in the mould boxes to create the casting shape.

When liquid metal is poured into the mould, steam and volatiles are produced in the vicinity of the casting, and they vent through both the top and bottom of the mould. The volatiles burn in the bottom vents and occasionally at the mould top. The mould and pallet traverse a cooling tunnel for around 90 minutes, during which time the casting continues to cool and water, steam and gases may continue to escape from the mould.

The mould boxes edges are observed to suffer damage, known to be caused by corrosion, but only in the regions where the gases vent from the pallet car.

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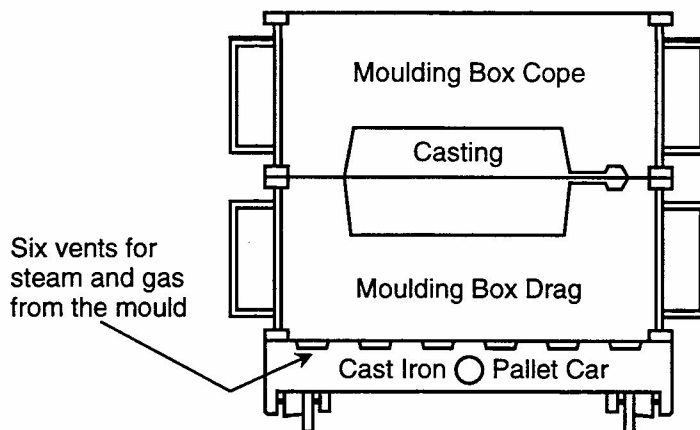
Figure 1: Schematic of the mould box and pallet car.

The edges of the mould have corrosion-resistant metal welded to them, but the corrosion pattern is still apparent.

The aim of this project is to investigate possible mechanisms that cause the corrosion damage and to develop strategies that decrease the corrosion effect(s) or even eliminate them.

2.   Possible mechanisms

Corrosion is, in general, a complicated process, and it is not possible in a study of this nature to consider the corrosion mechanisms in depth. There are several useful textbooks on corrosion (e.g. Evans, 1976; West, 1980) that are helpful, however, in describing general aspects of corrosion, and giving information about rates of corrosion in particular circumstances. Our approach to identifying the mechanisms of corrosion was to attempt to understand as many aspects of the casting process as possible, and assess whether any of them contribute to the corrosion.

The first observation we made was that, in normal operation, the mould boxes cycle around the casting line with a period of about 2 hours. During that time they are filled with sand, the metal is cast, cooled, the box is emptied and then cleaned ready for the next cycle. We also observed that, for around 10 minutes after the metal is poured into the mould, flames emanate from the grooves in the pallet car. The flames are caused by burning of the volatiles, and the combustion products form a "cocktail" of gases that can promote corrosion. While it is difficult to obtain a good estimate of the rate of corrosion, a "typical" rate of corrosion in such an environment would be about 50 mm/yr (West, 1980)

if it occurred continuously. If we consider that this type of corrosion, which we call *HOT Corrosion* occurs for only 10 minutes of a 2 hour cycle, and taking into account the number of hours per year the foundry operates, we find that a continuous corrosion rate of about 100 mm/yr would be required to account for the amount of corrosion that is occurring (known to be about 2 mm/yr). Thus we infer that *HOT Corrosion* is responsible for some of the damage that is occurring.

A third observation is that there is a considerable amount of moisture lying in the pallet car grooves while it traverses the cooling tunnel. This, presumably, leads to a high humidity environment in the vicinity of the mould box edges, which can promote corrosion. The presence of chloride ions in the water enhances the corrosion rate further. Toowoomba Foundry uses town water in the process, and this water has a relatively high chloride content. This type of corrosion, which we call *COLD corrosion*, can occur at rates of around 4–5 mm/yr (Evans, 1976) if the moisture has a moderate chloride concentration, but this rate is strongly dependent on the chloride concentration. Again, taking into account the time available for this type of corrosion to occur during a foundry cycle, we find that a rate of about 11 mm/yr would be required to account for the amount of corrosion that is occurring. So, we infer that *COLD corrosion* is responsible for some of the damage.

Another observation from the industrial representatives is that some sand can escape through the damaged sections during the process of filling the mould box with sand. The high pressure air forces the sand out. This phenomenon can occur only once the damage is sufficient to allow the passage of sand through the gaps between the cope and drag boxes. It was postulated that this type of sand "blasting" may wear the box edges and thus contribute to the problem. However, the fact that no such wear is seen on the cope boxes implies that wear is not an important mechanism. An important feature of corrosion, though, is that scale (the corrosion products) build up on the surface of the metal and can act as a protective layer. The sand-blasting effect may act to remove the scale, and thus providing a clean surface for corrosion to continue.

Similarly, the effect of cleaning the boxes once they are emptied may also be removing scale, and thus contributing to corrosion. It has been observed that the damaged areas show striations consisting of about 20 parallel, roughly equally spaced grooves along the damaged portions of the mould box edges. There appear to be too many such grooves across the width of the edges for them to be associated with the process of welding the edges. (All box edges have been welded with special hard metal material. This metal is applied as a wire run around the box edge. About 5 wire thicknesses are required to cover the edge, and it was speculated that variation in metal composition could account for the striations, but this was discounted.)

The cleaning process includes passing the mould box edges over a spinning wire brush, made of hard steel. The brush wires move in the same direction as the striations in the damaged sections, and we speculate that they cause the striations. A straightforward stability argument shows that once a groove has formed the wire strands will tend to slide into the deepest part of the grooves which deepens the grooves even further. In any case, the action of the brush would be to remove some scale and thus promote corrosion.

A final observation is that the damage pattern on the mould-box edge has another interesting characteristic — it is deepest in the centre (in the direction going from outside the box to inside). We believe this to be due to the effect of the *HOT corrosion*, for the following reason.

We assume that *HOT corrosion* occurs with a rate dependence of the form

$$r = kCe^{-E/RT} \tag{1}$$

where k is a rate constant, C is the concentration of a constituent of the burning volatiles that promotes corrosion, E is an activation energy, R is the universal gas constant and T is the temperature of the surface of the mould box, at which the reaction is occurring.

Now, we expect that the temperature of the mould box will decrease across the mould box edge, towards the outside of the box, and that the presence of the corrosion promoting contaminant may increase in the same direction. In that case, it is easy to show that r will, in general, have a maximum value across the edge thickness, leading to the concave corrosion pattern seen. This argument may be somewhat tenuous, because it is very difficult to know what are the constituents of the burning volatiles, but we expect that the oxygen content will increase from inside to outside the box, and that this will likely increase the corrosion rate, so that C may well represent oxygen concentration.

3.   Prevention strategies

In the remainder of this report we present some strategies for minimising or preventing the corrosion effects identified above and attempt some simple modelling approaches that may assist in evaluating their effectiveness.

3.1   Venting

The volatile gas that is generated when the molten metal is poured escapes from both the top and bottom of the mould boxes. It is only at the bottom of the

boxes that these gases cause a problem with corrosion, so we wish to investigate whether it is possible to divert a significant amount of the volatile gases from escaping to the lips of the bottom of the mould (where the corrosion is occurring) by the strategic placement of vents in the sand mould. The moulds themselves are comprised of compacted moist sand containing coal dust and vents could be stamped into the compacted sand at the same time as the mould pattern. When the molten metal is poured into the mould the gas, comprised of air, water vapour and volatiles, at the molten metal/sand interface will undergo a rapid increase in pressure. The equations which describe the mechanisms of general heat and mass transfer through a multiphase system are reasonably well known and could in principle be solved by a number of techniques, probably involving numerical methods. Here we avoid any complex modelling of the multiphase system and examine the effectiveness of the vents by the following simplified problem.

Consider a porous medium, Ω, in two dimensions, containing a single gas phase under pressure at a boundary, Γ_1. On the boundaries Γ_2 zero flux conditions are imposed and at the porous medium/atmosphere boundaries, Γ_3, the gas pressure is set to atmospheric. We assume that the gas phase is governed by Darcy's Law:

$$\mathbf{q} = -\frac{K}{\mu}\nabla p, \tag{2}$$

where $\mathbf{q}$ is the specific discharge, K is the intrinsic permeability of the porous medium, μ is the viscosity of the gas phase and p is the pressure relative to the atmosphere. The domain and boundaries, showing a rough placement of the air vent, are shown in Figure 2. Assuming also incompressible flow, i.e. $\nabla.\mathbf{q} = 0$, the problem can be posed in the nondimensional form

$$\nabla^2 p = 0, \qquad \mathbf{x} \in \Omega \tag{3}$$

$$p = 1, \quad \mathbf{x} \in \Gamma_1; \qquad \mathbf{n}.\nabla p = 0, \quad \mathbf{x} \in \Gamma_2; \qquad p = 0, \quad \mathbf{x} \in \Gamma_3 \tag{4}$$

where $\mathbf{n}$ is the unit outward normal vector on Γ_2 and we have ignored the gravitational term. This is a standard problem and can be solved either analytically (e.g. using conformal mapping techniques) or numerically. We use the finite element package *Fastflo* to obtain the pressure solution and then calculate the streamlines shown in Figures 3 and 4. From the streamlines one can get an immediate indication of the tendency of flow of the gas. Figure 3 shows the flow trajectories for a vent with a relatively moderate depth of penetration into the mould. Only a relatively small amount of gas is diverted from escaping the lower boundary. Figure 4 shows an air vent placed closer to the source of gas (i.e. the edge of the casting) with a greater penetration. Most of the streamlines
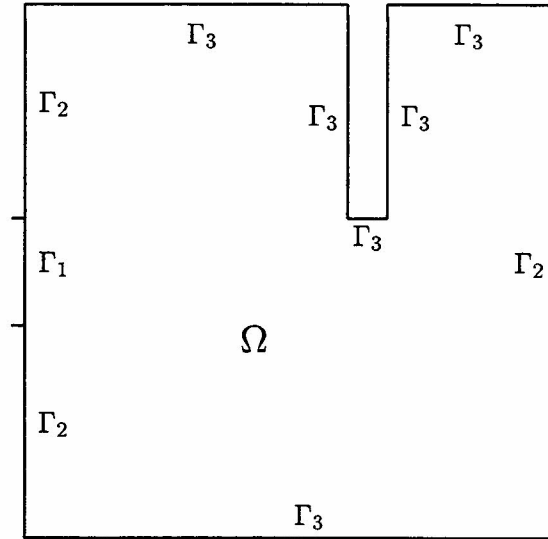
Figure 2: Definition of the solution domain, which represents half of a mould box. The casting, which causes the release of gas, is at the portion of the boundary marked Γ_1.

emanating from the boundary Γ_1 are intersected by the vent in this case, so most of the gas will be diverted away from the lower boundary.

Of course, a real casting has a complicated shape in three dimensions, so we expect that several such vents would be required to achieve sufficient diversion of gas away from the bottom of the mould. However, the principle of placing the vents close to the casting would still apply, but this would need to be carefully considered, in order that the integrity of the casting itself was not compromised by weakening the sand structure.

There are other possible means of re-directing the gas flow. During the course of the MISG, the Toowoomba Foundry representatives began to investigate means of diverting the gases away from the pallet grooves and into gaps in the sides of the boxes, where any effects of corrosion would be of no consequence to the process.

3.2 Groove ventilation

It is clear that the high humidity, due to the presence of moisture in the pallet grooves, increases the rate of *COLD corrosion*. Therefore, reducing the
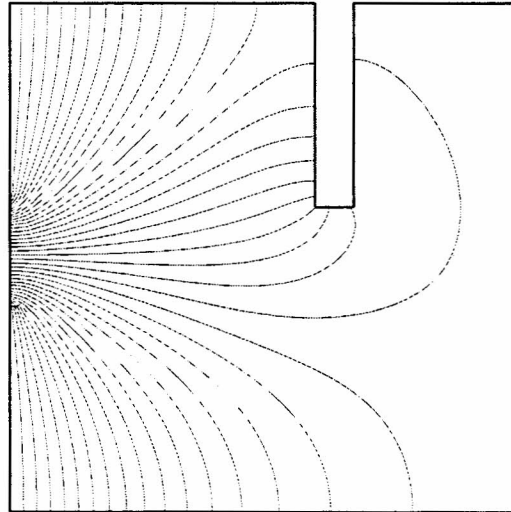
Figure 3: Calculated streamlines for a mould containing a vent with a moderate penetration.
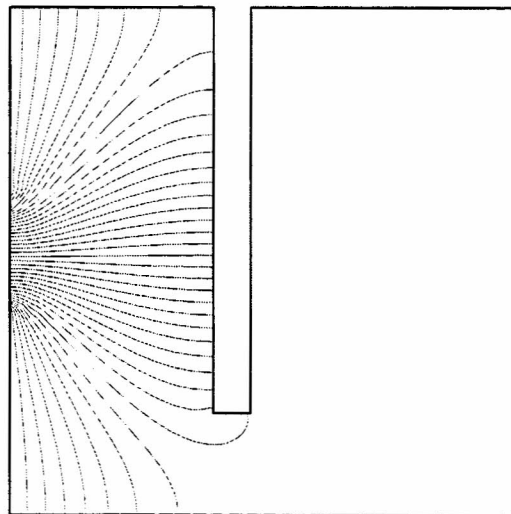

Figure 4: Calculated streamlines for a mould containing a vent that is both close to the source and has significant penetration into the mould.

humidity in the grooves of the pallet cars may significantly reduce the rate of *COLD corrosion.* One possible means of doing this would be to blow air along the grooves as the pallet cars traverse the cooling tunnel, where most of the *COLD corrosion* is likely to occur. Toowoomba Foundry representatives were considering the feasibility of devising a means of providing such ventilation.

3.3 Chloride reduction

The presence of chloride in the water supply may be a significant factor in the corrosion. In fact, the concentration of chlorides in the damp sand may be considerably higher than that in the water. To appreciate this, we again need to consider the process. After a casting is removed from a mould box, some of the sand used is lost, due to it being attached to the casting. Sand is therefore added to make up that which is lost. In addition, water is added to the mould box during a water cooling stage. If we assume that all of the chloride in the water attaches to the sand, then chloride in the sand continually increases, as shown by the difference formula

$$V_b c_{i+1} = V_b c_i + V_l \frac{\rho_s}{\rho_w} f_m c_w + V_w c_w - V_l c_{i+1} \tag{5}$$

where c_i is the chloride concentration of the sand after being used i times in a mould, V_b is the volume of sand in the box, V_l is the volume of sand lost (and consequently the volume added back in), ρ_s is the bulk density of the sand, ρ_w is the density of water, f_m is the mass fraction of moisture in the added sand, V_w is the volume of water added, per box, during cooling and c_w is the chloride content of the town water supply.

The solution of this difference equation has a limiting value of

$$c_L = \frac{V_l \frac{\rho_s}{\rho_w} f_m + V_w}{V_l} c_w \tag{6}$$

and using estimates of the quantities in the above equation we find that

$$c_L \approx 4 c_w$$

and, as noted before, the chloride concentration in the incoming town water supply is already high.

While this looks slightly alarming, it must be noted that we have assumed the chloride ions remain attached to the sand, but if this is the case then they will not be in solution, where they can contribute to corrosion. As a result, it is not clear that the build-up of chloride ions in the sand is necessarily deleterious. The

only solution to reducing the chloride ions in the system is to use water with a low chloride content. This would require the demineralisation of all water used in the mould line, which we were assured by the industry representatives is economically not practical.

3.4 Brush modification

Should our observation relating to striations in the damaged areas be correct, then it would be desirable to consider modifying the method of cleaning the mould box ends, particularly in the region of the corrosion damage. This may prevent removal of scale on the damaged portions, and may also eliminate the striations.

4. Discussion

Although we have identified plausible mechanisms for the corrosion occurring on the mould box ends, and have suggested strategies aimed at reducing the corrosion, we have been unable to clearly quantify the effects. We have shown that both *HOT* and *COLD corrosion* can contribute to the damage, but it proved impossible to determine whether one type dominated the other. There is a tradeoff between the high corrosion rate of *HOT corrosion* with its short duration, and the lower corrosion rate of *COLD corrosion* with a considerably longer duration. Nevertheless, we would expect that with a combination of the strategies suggested above, the amount of corrosion should at least be reduced.

Acknowledgements

References

U.R. Evans, *The Corrosion and Oxidation of Metals* (Edward Arnold, 1976).

J.M. West, *Basic Corrosion and Oxidation* (Ellis Horwood, 1980).