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CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

9.1 CONCLUSIONS

At the commencement of the current work the hardfacing industry did not have a systematic procedure for predicting the most important features of a hardfacing overlay, namely the composition and geometry. The current work has culminated in the first set of working principles for the deposition of high-chromium white iron surface layers comprising overlapping beads. It is anticipated that these principles will significantly increase the level of predictability in hardfacing operations, as it is now possible to predict the composition and many of the geometric features of an overlay prior to deposition.

One of the major findings of the current work was that the control of dilution in single-bead deposits and multi-pass overlays are fundamentally different problems. In single-bead deposits minimum dilution can be achieved by minimising the ratio of substrate melted to material deposited, regardless of the dimensions of the bead. In multi-pass overlays, however, there is a height constraint that changes the nature of the problem, so that the objective is to minimise the average penetration subject to the constraint that the overlay height is fixed.

The dilutions of single-bead deposits are adequately predicted by the Bednarz-Deam model. This model resulted in a form of expression that is consistent with observations of experiments both in the current work and in previous studies. The form of expression was also found to be consistent with the expression for the width of a single bead that was developed in the current work.

Two models were developed in the current work for predicting dilution in multi-pass overlays. The trends in the output from these models were consistent with one another. In fact, the geometric model described in chapter 7 provided accurate predictions of average overlay penetrations directly from first principles. The accuracy of these predictions and the close agreement between the models provided a level of confidence in the output and, as such, the output could be used to draw conclusions and identify trends over a broader range of conditions. Some of the major findings regarding multi-pass overlays were:

- The range of achievable dilutions is a function of the average height of the overlay, with the probability of achieving a low-dilution deposit increasing with increasing overlay height. Consequently, the overlay height also largely determines the range of achievable microstructures and the range of achievable wear performances.
- For an overlay of a given height, the selected welding parameters determine where the dilution lies within the achievable range.
- The two parameters with the strongest effect on overlay dilution are the travel speed and the welding current. Higher travel speeds reduce the dilution of a multi-pass overlay. Reductions in welding current also reduce the dilution but at the expense of deposition rate. In most hardfacing operations the appropriate balance will need to be achieved between wear performance and productivity.

Another parameter that can have a significant bearing on the dilution is the inter-pass temperature. If the component being hardfaced is not allowed to cool adequately between successive passes, the inter-pass temperature will rise and so too will the dilution. Cumulative heating of the work piece can result in large temperature excursions and large variations in wear performance. Care needs to be taken to ensure that, either through cooling systems or the appropriate delays, the inter-pass temperature is maintained within acceptable limits. Care is also necessary when depositing overlays bi-directionally. If the welding head commences each pass immediately after completing its predecessor, the end of the previous bead has not had sufficient time to cool and large variations in dilution can be expected.

With respect to the wear performance of hardfacing weld deposits, a significant observation was made in that the eutectic carbides may not offer the same benefits to wear resistance as the primary carbides. It has been reported previously (Diesburg and Borik, 1974) that fine eutectic structures, which form at high solidification rates, offer inferior abrasion resistance to that offered by coarser structures. The experimental results obtained in the current work are consistent with this report. Consequently, in applications where high volume fractions of carbides are beneficial, it is important to ensure that the microstructure is strongly hypereutectic, so that primary carbides are present in sufficient quantities to provide the desired benefits to wear performance.

For a given abrasive wear system, it is possible to predict the wear performance in service provided that one has access to three previous wear results, the all-weld-metal composition for the consumable and its deposition characteristics. A general form of expression for the apparent wear resistance of a high-chromium white iron in a given wear system was proposed.

A link between the selected welding parameters, deposit microstructure and the resulting abrasion resistance has now been established.

9.2 SUGGESTIONS FOR FUTURE RESEARCH

In the course of this study several areas were identified as warranting further investigation. The following areas deserve specific mention:

- The relationship between deposition rate and welding parameters such as voltage, current and work distance requires further work. It is known (Kiyohara *et al.*, 1980) that the welding voltage does affect the deposition rate but none of the equations presented in the literature incorporate any voltage effects. At present it is possible to achieve the correct overlay height by setting the deposition rate directly. (The deposition rate can be set by the correct choice of wire feed rate and knowledge of the deposition efficiency.) However, for a given wire feed rate, it is necessary to predict the current that will be drawn from the welding power supply in order to estimate the resulting penetration and hence dilution with sufficient accuracy. It is anticipated that an improved understanding of the factors that affect the deposition rate will bring benefits to both hardfacing and the broader field of welding science.
- The factors affecting the distribution of heat in arc welding of dissimilar metals are not well understood. Further work is required to establish the

causes of, and to quantify, any biases that may arise in the melting of each material.

- It may not always be practical to deposit an overlay exclusively in the down-hand position. It would be valuable to extend the principles developed in the current work to out-of-position welding.
- The possibility arises for an alternative process to bring further improvements to the control of dilution and hence the wear performance of overlays. At present it is not possible to control the deposition rate independently of the amount of substrate that is melted by virtue of the fact that the welding current is intimately related to both of these quantities. If the heat delivered to the substrate were to be divorced from the deposition rate by employing alternative technology (*i.e.* a process other than a consumable-electrode process) it is possible that a greater degree of control over dilution will be achieved.
- The field trials demonstrated that, when exposed to impact, single-layer hypereutectic white iron overlays are susceptible to spalling and fracture. Further work is required to establish whether this is a general characteristic of hypereutectic weld deposits or whether the root cause lies elsewhere. For example, the residual stresses in single-layer hypereutectic overlays may be sufficient in themselves to cause spalling, and significant improvements may be observed if a hypereutectic second layer were to be deposited on to a high-dilution buffering layer. Another possible cause for the apparent susceptibility of hypereutectic deposits to spalling is the formation of the

complex regular microstructure. If an interlinked carbide network were present, it would provide continuous paths for crack propagation.

- Further work is required to compare the wear performance of complex regular microstructures with conventional hypereutectic microstructures that have equivalent total carbide volume fractions. Very little is known about the wear properties of complex regular white-iron microstructures.