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a	fitted parameter for deposition rate equation (eq. 2.4)
A	cross-sectional area of a weld bead
$a_1, \dots, a_5$	fitted constant terms or indices (general)
A_d	cross-sectional area of weld bead resulting from material deposited in that pass
A_m	cross-sectional area of material that is melted in an overlapping bead, excluding the area that is contributed by material that is deposited in that pass
$A_{s(ov)}$	cross-sectional area of substrate melted per pass in a multi-pass overlay under steady-state conditions
$A_{s(sb)}$	cross-sectional area of substrate melted in a single-bead deposit
A_{st}	cross-sectional area of steel melted
A_{wi}	cross-sectional area of white iron melted
b	fitted parameter for deposition rate equation (eq. 2.4)
B	width of steel substrate (Fig. 5.5)
$b_1, \dots, b_5$	fitted constant terms or indices (general)
$[C]$	carbon concentration in the deposit
C_1, C_2	fitted parameters for bead width equation (eq. 3.4)
$[C]_{awm}$	carbon concentration in an all-weld-metal deposit
$[C]_{eut}$	average carbon concentration in the eutectic constituent
$[C]_m$	average carbon concentration in the matrix constituent
$[Cr]$	chromium concentration in the deposit
$[Cr]_{awm}$	chromium concentration in an all-weld-metal deposit
d	diameter of welding consumable
D	dilution of a weld deposit (general)
D_1	steady-state dilution of first layer
D_2	steady-state dilution of second layer with respect to substrate
$D_{2/1}$	steady-state dilution of second layer with respect to first layer

D_{av}	average dilution of a multi-pass deposit
$D_{n(sb)}$	normalised single-bead dilution
D_{ov}	steady-state dilution of a multi-pass overlay
D_{sb}	single-bead dilution
$D_{sb/wi}$	dilution of a single bead deposited on to white iron
E_{fm}	change in enthalpy required to melt filler material
E_s	change in enthalpy required to melt substrate
f	wire feed rate
$F(\,)$	a mathematical function (eq. 3.2)
G	gas flow rate
h	single-bead height
H_{av}	average height of a multi-pass deposit
H_p	peak height of a bead in a multi-pass overlay under steady-state conditions
H_{ss}	average height of a multi-pass overlay under steady-state conditions
HD_{com}	hardness of a composite material
HD_c	microhardness of the carbide phase
HD_m	microhardness of matrix constituent
I	welding current
k	area fraction of a bead contributed by material deposited in that pass
K	fitted constant parameter (eq. 2.6)
$k\square$	thermal conductivity
l	work distance
L	length of an overlay
m	mass of welding consumable per unit length
n	dimensionless operating parameter
N	number of beads in an overlay
p	single-bead penetration
P_{av}	average penetration of a multi-pass deposit

P_{ss}	average penetration of a multi-pass overlay under steady-state conditions
$PCVF$	primary carbide volume fraction
q	fitted parameter in wear resistance equation (eq. 4.5)
R	peak-to-valley ripple for a multi-pass overlay under steady-state conditions
S	travel speed
t	total welding time
T_o	initial substrate temperature
T_c	chosen reference temperature
$TCMF$	total carbide mass fraction
$TCVF$	total carbide volume fraction
V	welding voltage, measured from the contact tip to the work piece
V_a	arc voltage
V_{fm}	volume of filler material deposited in a single pass
v	volume fraction of the reinforcing phase present in the material
v_i	volume fraction of i^{th} phase present in the material
w	single-bead width
w_n	normalised single-bead width
W	deposition rate
W_c	wear rate of a composite material
W_c^{-1}	apparent wear resistance of a composite material
$W_{dendrites}^{-1}$	apparent wear resistance of dendrites
$W_{eutectic}^{-1}$	apparent wear resistance of eutectic constituent
W_i	wear rate of i^{th} phase
W_i^{-1}	apparent wear resistance of i^{th} phase
W_m	wear rate of matrix constituent
W_m^{-1}	apparent wear resistance of matrix constituent
$W_{primary\ carbides}^{-1}$	apparent wear resistance of primary carbides
W_r	wear rate of reinforcing constituent

W_r^{-1}	apparent wear resistance of reinforcing constituent
w^*	width of melting parabola in geometric model
$[x]_{awm}$	concentration of element x in an all-weld-metal deposit
$[x]_{bm}$	concentration of element x in the base material
$[x]_i$	concentration of element x in the i^{th} bead of a multi-pass overlay
$[x]_{ss}$	concentration of element x in a multi-pass overlay under steady-state conditions
z	width of the parabolic function representing the steady-state bead profile
$\square$	fitted parameter for single-bead dilution equation (eq. 2.2)
$\square\square$	thermal diffusivity
$\square$	fitted parameter for single-bead dilution equation (eq. 2.2)
$\square$	$A_{s(ov)}$ as a fraction of $A_{s(sb)}$ for a matching single-bead deposit
$\square$	step-over between adjacent weld beads in a multi-pass overlay
$\square_a$	arc efficiency
$\square_d$	deposition efficiency
$\square_m$	melting efficiency
$\square$	bead wetting angle (see Figure 3.4(b))
$\square_g$	gun angle
$\square_r$	angle of rotation used in geometric model
$\square$	area fraction of a bead contributed by material from the previous bead
$\square$	density of an all-weld-metal deposit
$\square_c$	density of carbide phase
$\square_m$	density of matrix constituent
$\square$	overlap between adjacent weld beads in a multi-pass overlay

ABSTRACT

This study examines the mechanisms controlling the dilution, geometry and wear performance of weld-deposited high-chromium white iron surface layers. These layers are often deposited on steel components when resistance to abrasion is required. Manual-metal-arc welding (MMA) and flux-cored-arc welding (FCAW) are the processes most frequently employed to deposit such overlays. This work focuses on layers deposited by mechanised FCAW, as this process achieves higher deposition rates than MMA welding and affords a greater degree of control over individual welding variables.

Attention is first given to the factors affecting the dilution and geometry of single-bead deposits. The work presented in previous studies is reviewed and the findings are explained with reference to the welding literature. The findings of previous studies are also compared with results obtained in the current work. Expressions for the single-bead width and height are presented.

The wear performance of high-chromium white iron weld deposits is addressed. Wear testing was conducted both under laboratory conditions and in a series of field trials. The results of both sets of experiments are presented. The observed trends are then discussed and compared with the results of previous studies.

The mechanisms controlling dilution in multi-pass overlays were found to be different to those controlling the dilution of a single-bead deposit. Consequently, two distinct approaches were developed for predicting dilution in multi-pass overlays deposited in the

down-hand position. The first approach is semi-empirical and the second is based on first principles and geometry. The trends in the output data from each model were in close agreement. This agreement and the accuracy of the predictions provided a level of confidence in the output and, as such, the models could be used to draw conclusions and identify trends over a broader range of welding conditions.

This work culminates in what is believed to be the first set of working principles for the deposition of high-chromium white iron multi-pass overlays. Until now, the two most important features of a multi-pass overlay, namely the composition and geometry, had been determined by a trial-and-error process or retrospectively. It is believed that these principles will substantially improve the production and performance of weld overlays.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

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PUBLICATIONS

Portions of this work appear in the following articles:

- ARNOLD, B.K., BEDNARZ, B., FRANCIS, J.A., JONES, E.P. and BEE, J. (1998): “Principles for Weld Deposition of Hardfacing – Field Trials”, CRC Project 95:23, Final Report – Part 2.

- FRANCIS, J.A. and JONES E.P. (1997): “The Influence of Welding Parameters on the Wear Performance of High Chromium White Iron Hardfacing Alloys”, *WTIA National Seminars*, July, Mackay, Australia.

- FRANCIS, J.A., BEDNARZ, B., ARNOLD, B.K., JONES, E.P. and BEE, J. (1998): “Principles for Weld Deposition of Hardfacing”, CRC Project 95:23, Final Report – Part 1.

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- YELLUP, J.M., ARNOLD, B.K., FRANCIS, J.A. and BEE, J.V. (1996): “Development of a Hardfacing Procedure – The Significance of Welding Parameters”, *WTIA National Seminars*, July - August, Gladstone, Perth and Newcastle, Australia.

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