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Weld path optimisation for rapid prototyping and wear replacement by robotic gas metal arc welding

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WELD PATH OPTIMISATION FOR RAPID PROTOTYPING AND WEAR REPLACEMENT BY ROBOTIC GAS METAL ARC WELDING

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Certification

I, Michael R. Siminski, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Michael R. Siminski

"The threshold of transformation is always the experience of one's limitations"

McGrath, S., 1992. "The Passion According to Tolkien",

in *Tolkien: A Celebration*, Pearce, J. (ed.), Fount, London, 1999.

"Now all has been heard; here is the conclusion of the matter:

Fear God and keep his commandments, for this is the whole duty of man"

Ecclesiastes 12:13

Abstract

Rapid prototyping (RP) is a large and rapidly growing industry with many different processes either under development or already available commercially. These processes offer fast and flexible production of objects from a wide range of materials. They vary from being able to produce only prototypes of products, through to being suitable for production of finished products ready for service. Rapid prototyping by robotic gas metal arc welding (GMAW) uses metal deposited by the GMAW process to build metal products with engineering properties suitable for service conditions.

Wear replacement (WR) involves the repair of worn metal surfaces through the deposition of weld metal, and can also be performed using robotic GMAW. Since both rapid prototyping and wear replacement by robotic GMAW involve the building up of metal objects from metal deposited by the GMAW process, it is possible to combine research in this area.

Rapid prototyping and wear replacement using the robotic GMAW process may however give rise to stability problems. Geometric and thermal instability can be an inherent feature of the process, resulting in relatively poor dimensional accuracy and surface quality. Various research directions have been taken in the past in order to address these problems, however the effects of weld path design on process stability have not yet been well researched.

The objective of this thesis was to study what effects weld path design can have on the stability of rapid prototyping and wear replacement by GMAW, in order to test whether weld path design could be used to improve process stability and performance. The hypothesis adopted in this thesis was that improved geometric and thermal stability should be possible if the material and heat input are optimised by control of the weld path through weld path design.

It was found that the stability of the rapid prototyping and wear replacement by GMAW process is very sensitive to weld path design and that optimised open-loop weld path design can be used to greatly improve process stability and performance. A number of different mechanisms were identified through which the weld path design impacts on the stability and performance of the process and corresponding recommendations for weld path design were presented. The suitability of various weld path designs for different types of applications was assessed and the most optimal weld path designs for an expected wide range of applications were identified. By using one of the most recommended path strategies, rapid prototyping and wear replacement by

GMAW systems can enjoy improved geometric and thermal stability and fewer problems with weld defects, through the choice of weld path.

It was predicted that the most successful commercial rapid prototyping and wear replacement by robotic GMAW systems would utilise a flexible and multi-faceted approach, using a combination of technologies, in order to best address the various needs of the process as required for key areas of industrial application.

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Contents

Nomenclature

CE	Carbon equivalent (also CEQ)
FCAW	Flux cored arc welding
FDM	Fused Deposition Modelling rapid prototyping process
GFR	Gas flow rate [L/s]
GMA	Gas metal arc
GMAW	Gas metal arc welding
GTAW	Gas tungsten arc welding (also TIG)
HAZ	Heat affected zone
LENS	Laser Engineered Net Shape rapid prototyping process
MAG	Metal active gas (welding) - GMAW
MIG	Metal inert gas (welding) - GMAW
MMAW	Manual metal arc welding
p value	Probability of making a type-1 error arising from a statistical test
R_a	A measure of surface roughness [Kalpakjian, 1989]
Ridge weld	One of the two weld types in the self-constrained welding strategy
RP	Rapid prototyping - usually referring to RP by robotic GMAW
R_q	A measure of surface roughness [Kalpakjian, 1989]
R_t	A measure of surface roughness [Kalpakjian, 1989]
SAW	Submerged arc welding
SDM	Shape Deposition Manufacturing rapid prototyping process
SLA	Stereolithography rapid prototyping process
SLS	Selective Laser Sintering rapid prototyping process
Standoff	Contact-tip to workpiece distance
Stickout	Electrode extension past contact-tip
Trough weld	One of the two weld types in the self-constrained welding strategy
TS	Welding travel speed [mm/s]
WFR	Wire feed rate [mm/s]
WR	Wear replacement - usually referring to WR by robotic GMAW
WTIA	Welding Technology Institute of Australia

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