Ultrasonic Inspection of Gas Porosity Defects in Aluminium Die Castings

by

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A thesis submitted to the Industrial Research Institute Swinburne, Swinburne University of Technology in fulfilment of the requirements to the degree of Doctor of Philosophy

Hawthorn, Melbourne, Australia

July 2006

DECLARATION

This thesis contains no material that has been accepted for the award of any degree or diploma in any university or college of advanced education, 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.

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Date: 17/7/2006

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to the Co-operative Research Centre for Cast Metals Manufacturing (CRC CAST) and the participating companies Nissan Casting Australia Pty. Ltd., (Mr. Ken Porter and Mr. Leng Lim) and the Ford Motor Company Australia Pty. Ltd., (Mr. Darren Mathews) for their support, and access to testing equipments and castings throughout the research program.

The author is grateful for the support obtained from both his supervisors, Prof. Romesh Nagarajah and Dr. Pio Iovenitti at the Industrial Research Institute Swinburne (IRIS), all the way through this project. In particular, Prof. Romesh Nagarajah bestowed constant guidance and encouragement with this thesis. Valuable support was also obtained from NDT researchers, Mr. Howard Morton and Mr. Peter Virtue at Defence Science and Technology Organisation, Melbourne.

The author wishes to acknowledge the support received from the Metallurgical, Laser, Micro-tech and Non-contact inspection research groups and technicians (Mr. Brian Dempster) at IRIS. He also wishes to thank his research colleagues, especially Dr. Kynan Graves at IRIS, and Dr. Chinnu Subramaniam for their constant encouragement especially in difficult times.

The author has benefited greatly from discussions with other research groups (CSIRO, Monash University) and its members within the CRC CAST. He thanks Mr. Paul Spurling for proof reading the thesis.

Finally, the author would like to express his gratefulness to his mother Mrs. P. Bagyalakshmi and late father Mr. P.M. Palanisamy, and constant encouragement from his wife Mrs. Kothainayaki and also other family members for their support, patience and endurance, which have enabled him to achieve his goal.

Abstract

This thesis documents a PhD research program undertaken at Swinburne University of Technology between the years 2000 and 2004. The research was funded by the Cooperative Research Centre for Cast Metals Manufacturing and was undertaken in collaboration with Nissan Casting Plant Australia Pty Ltd and the Ford Motor Company Australia Limited. This thesis reports on the investigation of the possibility of using an ultrasonic sensing-based, non-destructive testing system to detect gas porosity defects in aluminium die casting parts with rough surfaces. The initial intention was to develop a procedure to obtain ultrasonic signals with the maximum possible amplitude from defects within the rough surface areas of the castings. A further intention was to identify defects with the application of a suitable signal processing technique to the raw ultrasonic signal. The literature review has indicated that ultrasonic techniques have the potential to be used to detect sub-surface defects in castings. The possibility of classifying very weak ultrasonic signals obtained from rough surface sections of castings through a neural network approach was also mentioned in the literature. An extensive search of the literature has indicated that ultrasonic sensing techniques have not been successfully used to detect sub-surface defects in aluminium die castings with rough surfaces.

Ultrasonic inspection of castings is difficult due to the influence of microstructural variations, surface roughness and the complex shape of castings. The design of the experimental set-up used is also critical in developing a proper inspection procedure. The experimental set-up of an A-scan ultrasonic inspection rig used in the research is described in this thesis. Calibration of the apparatus used in the inspection rig was carried out to ensure the reliability and repeatability of the results. This thesis describes the procedure used to determine a suitable frequency range for the inspection of CA313 aluminium alloy castings and detecting porosity defects while accommodating material variations within the part. The results obtained from ultrasonic immersion testing indicated that focused probes operating at frequencies between 5 MHz and 10 MHz are best suited for the inspection of castings with surface roughness R_a values varying between 50 μm and 100 μm. For

the purpose of validating the proposed inspection methodology, gas porosity defects were simulated through side-drilled holes in the in-gate section of selected sample castings. Castings with actual porosity defects were also used in this research.

One of the conclusions of this research was that it was extremely difficult to detect defects in castings with surface roughness above 125 μm. Once the ultrasonic signal data was obtained from the sample aluminium die castings with different surface roughness values ranging from 5 μm to 150 μm, signal analysis was carried out. Signal feature extraction was achieved using Fast Fourier Transforms (FFT), Principal Component Analysis (PCA) and Wavelet Transforms (WT) prior to passing the ultrasonic signals into a neural network for defect classification. MATLAB tools were used for neural network and signal pre-processing analysis. The results indicated that poor classification (less than 75%) was achieved with the WT, PCA and combination of FFT/PCA and WT/PCA pre-processing techniques for rough surface signals. However, the classification of the signals pre-processed with the combination of WT/FFT, FFT/WT and FFT/WT/PCA classifiers provided much better classification of more than 90% for smooth surface signals and 78% to 84% for rough surface signals. The results obtained from ultrasonic testing of castings with both real and simulated defects were validated with X-ray analysis of the sample castings. The results obtained from this research encourage deeper investigation of the detection and characterisation of sub-surface defects in castings at the as-cast stage. Implications for the industrial application of these findings are discussed and directions for further research presented in this thesis.

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List of Acronyms

Symbol	Description
AI	Artificial Intelligence
ANN	Artificial Neural Networks
BP	Back Propagation
BWE	Back Wall Echo
CRC CAST	Cooperative Research Centre for Cast Metals Manufacturing
CRT	Cathode Ray Tube
CWT	Continuous Wavelet Transform
DFT	Discrete Fourier Transform
DWT	Discrete Wavelet Transform
ECT	Eddy Current Testing
FFT	Fast Fourier Transform
FSH	Full Screen Height
HPDC	High Pressure Die Casting
ISO	International Standard Organisation
KBIS	Knowledge Based Inspection System
LPT	Liquid Penetrant Testing
LSF	Line Spread Function
MPT	Magnetic Particle Testing
MSE	Mean Square Error
MTC	Manual Transmission Case
NDE	Non Destructive Evaluation
NDT	Non Destructive Testing
NDT&E	Non Destructive Testing & Evaluation
PCA	Principal Component Analysis
QS	Quality Standards
ROI	Region Of Interest
RT	Radiographic Testing

SCG	Scaled Conjugate Gradient
SD	Standard Deviation
SOSP	Structural Oil Sump Pan
SUT	Swinburne University of Technology
TOFD	Time of Flight Diffraction
TQM	Total Quality Management
UT	Ultrasonic Testing
WP	Water Path
WT	Wavelet Transform

List of Variables

Symbol	Description	Unit
α	Ultrasonic Angle Beam Spread	º
λ	Wavelength of the Signal	mm
ϕ_L	Incident Angle of the Longitudinal Beam	º
ϕ_S	Reflected Shear Beam Angle	
b	Neural Network Bias	
D	Diameter of Transducer	mm
F	Frequency of Ultrasound Signal	MHz
F	Focal Length of the Transducer	mm
L	Total Attenuation of Ultrasonic Signal	dB/mm
L_{Diff}	Ultrasonic Beam Spread Loss	dB/mm
L_{Grain}	Grain Scattering Loss	dB/mm
L_{Imp}	Double Transmission Loss of Ultrasonic Signal	dB/mm
L_p	Attenuation Loss Due to Porosity	dB/mm
L_{Surf}	Surface Roughness Loss	dB/mm
MP	Material Path	mm
N	Near Field Length	mm
P_R	Neural Network Input	
h_{RMS}	Root Mean Square of Surface Roughness Heights	μm
R_1	Acoustic Impedance in Water	kg/m^2s
R_2	Acoustic Impedance in Aluminium Material	kg/m^2s
R_a	Arithmetic Mean Surface Roughness	μm
T	Time Period	s
T	Target Output in Neural Network	
V	Velocity of Ultrasound in the Material	m/s
V_L	Velocity of Longitudinal Beam	m/s
V_m	Velocity of Ultrasound in Aluminium Material	m/s

V_S	Velocity of Shear Beam	m/s
V_w	Velocity of Ultrasound in Water	m/s
w	Neural Network Weights	
z	Acoustic Impedance	kg/m^2s