THERMAL FATIGUE OF LASER MODIFIED TOOL STEELS MOULD SURFACE AT HIGH TEMPERATURE

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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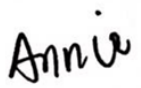
STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.



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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Manufacturing and Mechatronic Engineering Technology

UNIVERSITI MALAYSIA PAHANG

JULY 2020

ACKNOWLEDGEMENTS

My deep gratitude goes first to my research supervisor, Dr. Izwan Bin Ismail who always give me patient guidance in completing my Master's degree project. I would like to thank my research supervisor for giving me constant support, suggestion, correct my mistakes and spending his time at every stage of my research. I feel grateful to have a respectful supervisor that led me through this research study.

I also would like to take this opportunity to acknowledge technicians from Faculty of Manufacturing Engineering, Faculty of Mechanical Engineering and Central Laboratory UMP. Due to their support and guidance, I success overcome the problems that I had faced and completed my Master's degree project. Also not forgotten, I would like to thank En. Abdul Fattah Bin Mohd Tahir from Kolej Kemahiran Tinggi MARA (KKTM) for his help and training.

Furthermore, I would like to express my thanks to my parents for giving me support, encouragement and love. They always sacrifice themselves to provide me with economic support on my accommodation and study so that I can focus on my project. They also inspired me when I feel tired and faced problems throughout my research study. Without them, I cannot achieve my targets.

Moreover, my sincere thanks also go to all my friends, Fazliana Binti Fauzun, James Lau and Hazim who always lend me their hand and encourage me. I cannot find appropriate words to express my appreciation for their helping and support but I will keep them in my heart.

ABSTRAK

Dalam persekitaran penuangan acuan, hayat acuan menurun disebabkan oleh hakisan, pengaratan, kelesuan haba dan pengoksidaan yang berlaku di permukaan acuan yang menyebabkan penurunan masa dan kerugian. Retakan akibat kelesuan haba adalah punca utama kegagalan acuan iaitu hampir 70%. Untuk mengurangkan retakan kelesuan haba, kekasaran permukaan (SR) dan kekerasan sampel perlu disesuaikan. Dalam kajian ini, kesan parameter pengubahsuaian permukaan laser pada SR dan kekerasan telah dikaji untuk mengurangkan retakan kelesuan haba. Kekerasan dan mikrostruktur untuk sampel yang diubahsuai dengan laser dan AISI H13 yang asal juga dikaji selepas ujian kelesuan haba. Pertama, DOE dengan faktorial penuh telah dijalankan. Tiga faktor yang diguna adalah kuasa puncak (W), kekerapan nadi lasik (PRF) dan kadar pertindihan (%) dengan julat 1500-1900W, 40-60Hz dan 10-30%. Lasik jenis fiber laser telah digunakan pada permukaan bahan keluli karbon tinggi AISI H13. SR dan kekerasan bagi semua sampel yang diubahsuai dengan laser telah diukur. Selepas itu, AISI H13 yang asal dan sampel yang diubahsuai dengan laser yang dipilih digunakan untuk menjalankan ujian kelesuan haba yang melibatkan ujian kitaran perendaman. Ujian kelesuan haba dilakukan dengan memanaskan sampel dalam aluminium cair pada julat suhu 850-900 °C dan menyejukkan dalam air pada suhu 27 °C secara berterusan. AISI H13 yang asal dan sampel yang diubahsuai dengan laser dikaji dari segi kekerasan, mikrostruktur dan retakan kelesuan haba sebelum dan selepas 5000 kitaran. Dari hasil kajian ini, kekerasan sampel yang diubahsuai dengan laser meningkat 3 kali kanda dari 203.3 HV hingga 744.6 HV. Walau bagaimanapun, SR juga meningkat dari 1.3 μm hingga julat 8.97-42.31 μm disebabkan oleh pelbagai parameter laser. Kadar pertindihan merupakan kesan yang penting terhadap kekerasan. Manakala, SR yang rendah diperoleh pada 1900 W kuasa puncak dan 10% kadar pertindihan. Walau bagaimanapun, PRF adalah parameter yang tidak ketara untuk mempengaruhi kekerasan dan SR. Model Ramalan telah dibangunkan untuk mengenal pasti penetapan parameter laser yang sesuai untuk nilai SR dan kekerasan. Kekerasan dan mikrostrktur bagi sampel diubahsuai dengan laser sebelum dan selepas ujian kelesuan haba telah disiasat. Kekerasan untuk sampel yang diubahsuai dengan laser menurun secara mendadak kerana mikrostruktur berubah. Walau bagaimanapun, sampel yang diubahsuai dengan laser menunjukkan prestasi yang lebih baik daripada AISI H13 yang asal. Sampel yang diubahsuai dengan laser telah berjaya mengurangkan bilangan dan panjang keretakan dari 27 hingga 17 dan 6.87 mm hingga 1.84 mm masing-masing. Sebagai kesimpulan, parameter laser yang sesuai dapat menghasilkan sampel dengan SR yang rendah dan kekerasan yang tinggi. Ujian kelesuan haba membuktikan bahawa kekerasan yang tinggi mempunyai rintangan tinggi terhadap kelesuan haba yang juga boleh mengurangkan retakan kelesuan haba. SR yang rendah juga boleh mengurangkan pengumpulan oksida yang boleh mengakibatkan retakan kelesuan haba berlaku. Secara keseluruhan, kajian ini amat penting untuk meningkatkan sifat permukaan seperti rintangan kelesuan haba dan kekerasan untuk bahan keluli karbon tinggi AISI H13 dalam aplikasi suhu tinggi.

ABSTRACT

In die casting environment, tool steel service life decrease due to the oxidation, erosion, corrosion and thermal fatigue cracks which occur on the die surface that cause production downtime and losses. Thermal fatigue cracks is a significant failure which is around 70% in die casting dies. In order to reduce the thermal fatigue cracks, the surface roughness (SR) and hardness of laser modified samples have to be tailored. In this study, the effect of laser surface modification parameters on SR and hardness was investigated to reduce the thermal fatigue crack. The hardness and microstructure of laser modified and as-received AISI H13 tool steels that subjected to the thermal fatigue test were also investigated. First, a full factorial design of experiment (DOE) was developed. The three factors were peak power (W), pulse repetition frequency (PRF) and overlap rate (%) with the range of 1500-1900W, 40-60Hz and 10-30% respectively. Then, fiber laser system with pulse mode was applied on the surface of AISI H13 tool steel. The SR and hardness of all the laser modified samples were then measured. After that, the as-received AISI H13 and selected laser modified samples were used to conduct a thermal fatigue test which involve cyclic immersion test. The thermal fatigue test was conducted by continuously heating the samples in molten aluminium and cooling in a water bath at a respective temperature range of 850-900 °C and 27 °C. The characterisation of as-received and laser modified samples for hardness, microstructure and thermal fatigue crack conducted before and after 5000 cycles. From the findings, the hardness of the laser modified samples increased 3 times from 203.3 HV to 744.6 HV. However, the SR has also increased from 1.3 µm to the range of 8.97-42.31 µm due to the various parameters of laser surface modification. The overlap rate has a significant effect on hardness. While, a low SR can be obtained at 1900 W of peak power and 10% of overlap rate. However, the PRF was an insignificant parameter to affect the hardness and SR. Prediction model was developed to identify suitable laser parameters setting for the intended value of SR and hardness. The hardness and microstructure of laser modified samples before and after thermal fatigue (TF) test were investigated. The hardness of laser modified samples decreased dramatically due to the microstructure changed. However, the laser modified samples significantly performance well than the as-received AISI H13. Laser modified samples reduce the number and length of cracks from 27 to 17 and 6.87 mm to 1.84 mm respectively. In conclusion, a suitable laser parameters setting can produce a low SR and high hardness sample. The thermal fatigue test proved that high hardness has a high resistance of thermal fatigue which can reduce the thermal fatigue cracks. Low SR can also reduce the accumulation of oxide which can generate the thermal fatigue cracks. Overall, this study is significant to enhance the surface properties such as resistance of thermal fatigue and hardness for AISI H13 tool steel in high temperature applications.

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LIST OF SYMBOLS

HV	Vickers hardness unit
v	Scanning speed
P_p	Peak power
P_{ave}	Average power
η	Overlap rate
L_c	Cut off value
L_t	Traversing length

LIST OF ABBREVIATIONS

AISI	American Iron and Steel Institute
BSE	Backscattered Electron Mode
C	Carbon
CNC	Computer Numerical Controlled
CO_2	Carbon Dioxide
Cr	Chromium
CW	Continuous Mode Laser
DOE	Design of Experiment
EDXS	Energy Dispersive X-Ray Spectroscopy
Fe	Iron
FESEM	Field Emission Scanning Electron Microscope
HAZ	Heat Affected Zone
LSE	Laser Surface Engineering
Mo	Molybdenum
MZ	Melted Zone
Nd:YAG	Neodymium-Doped Yttrium Aluminum Garnet
O	Oxygen
PACVD	Plasma-Assisted Chemical Vapor Deposition
PRF	Pulse Repetition Frequency
PVD	Physical Vapor Deposition
SEM	Scanning Electron Microscope
Si	Silicon
SR	Surface Roughness
TF	Thermal Fatigue
V	Vanadium
VC	Vanadium Carbide

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