EXPERIMENTAL AND STATISTICAL ANALYSIS FOR SURFACE MODIFICATION OF STEEL AND CAST IRON USING Nd:YAG LASER

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MASTER OF MECHANICAL ENGINEERING

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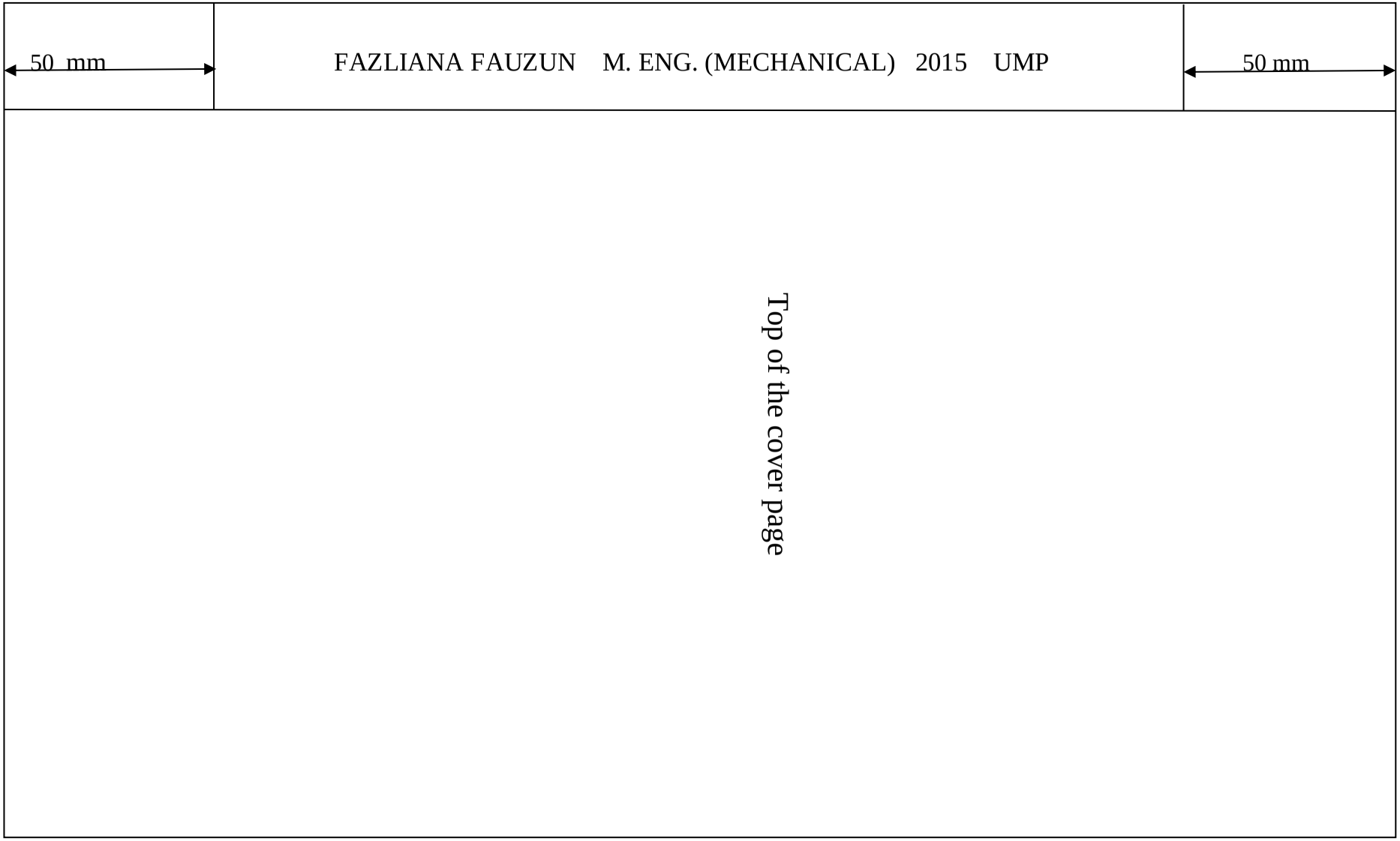
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Thesis submitted in fulfilment of the requirements
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LIST OF SYMBOLS

v	Laser Scanning Speed
τ	Pulse width
η	Overlapping rate
T	Laser period pulse
P_p	Peak power
P_{ave}	Average power
E	Laser energy
T_R	Laser residence time
I	Irradiance
F	Fluence
d	Spot size diameter
D	Thermal diffusivity
k	Thermal conductivity
C_p	Specific heat capacity
ρ	Density
DC	Duty cycle
A	Area of laser spot size
Ra	Roughness unit
Hz	Frequency unit
W	Watt
Hv	Vickers hardness unit

LIST OF ABBREVIATONS

AISI	American Iron and Steel Institute
ANOVA	Analysis of Variance
CNC	Computer Numerical Control
CO_2	Carbon dioxide
COILs	Chemical Oxygen Iodine Lasers
CVLs	Copper Vapour Lasers
CW	Continuous mode laser
DC	Duty Cycle
DOE	Design of Experiment
DN-PSO	Neighbourhood-Particle Swam Optimization
EDXS	Energy Dispersive X-Ray Spectrometry
FE SEM	Field Electron Scanning Microscopic
HAZ	Heat Affected Zone
HDPL	High power diode lasers
HPDD	High-power direct diode
LSM	Laser Surface Modification
Nd:YAG	Neodymium-Doped Yttrium Aluminium Garnet
PRF	Pulse Repetition Frequency
RSM	Response Surface Method
2D	Two dimensional
3D	Three dimensional
2FI	Two factors interaction

ABSTRACT

This thesis presents experimental study on laser surface modification of steel and cast iron to enhance surface properties. The aim of this study is to produce laser surface modified layer on AISI H13 tool steel, AISI 1025 low carbon steel and gray cast iron surface with enhance properties for die casting application. An Nd:YAG laser system with pulse processing mode was used to modify AISI 1025 low carbon steel, AISI H13 tool steel and gray cast iron samples. AISI 1025 low carbon steel was processed at four different parameters settings of average power, pulse repetition frequency (PRF), pulse width and scanning speed. AISI H13 tool steel and gray cast iron were processed using 3^3 full factorial design of experiment (DOE). The full factorial DOE, was designed using three factors namely peak power, PRF and scanning speed at three levels. The factors level for H13 were peak power ranged from 1.7 to 2.5 kW, PRF of 40 to 60 Hz and scanning speed of 1000 to 1400 mm/min. For cast iron, peak power ranged from 0.83 to 1.25 kW, PRF of 50 to 70 Hz and scanning speed of 1000 to 1400 mm/min. The as-received and laser modified surface was characterised for surface morphology, metallographic study, surface roughness and hardness properties. In metallographic study, samples were analysed for laser modified layer depth, focal position effect on modified layer depth and grain size. Results were analysed statistically using ANOVA. Optimisation of processing parameters for H13 tool steel and gray cast iron samples was conducted using Response Surface Method (RSM). A thermal stability test was conducted for H13 tool steel sample with the highest hardness properties at temperature range of 550 to 800 ^{o}C. From the findings, the laser modified surface depth in AISI 1025 low carbon steel, AISI H13 tool steel and gray cast iron samples ranged between 50.23 and 455.07 μm, 42.22 and 420.12 μm, and 67.97 and 157.69 μm respectively. Hardness for AISI 1025 was ranged from 255 to 460 $HV_{0.1}$ while hardness of AISI H13 tool steel modified layer ranged from 1000 to 1427 $HV_{0.1}$. Hardness of gray cast iron ranged from 250 to 450 $HV_{0.1}$. The minimum roughness, R_a, achieved in modified H13 was 1.10 μm, while in AISI 1025 and gray cast iron was 8.51 and 3.20 um. From thermal stability test, hardness of laser modified surface reduced to 512.8 $HV_{0.1}$ after heated at 800 ^{o}C. Statistical analysis shows significant quadratic and 2FI models produced for AISI H13 and gray cast iron samples responses. Optimization of DOE for H13 tool steel samples for minimum surface roughness and maximize hardness and modified depth properties resulted in 15 solutions. Optimisation for gray cast iron samples also was set into similar condition like H13 which resulted in 26 solutions. Limitation of temperature in applications can be determined from thermal stability test. At 800 ^{o}C, the hardness of laser modified layer found to be dropped 60 % which lower compared to previous works. These findings are significant to enhance surface properties of steel and cast iron for dies and high wear resistant applications.

ABSTRAK

Tesis ini membentangkan kajian eksperimen tentang pengubahsuaian permukaan keluli menggunakan lasik bagi menambahbaik sifat permukaan tersebut. Lasik jenis Nd:YAG berkuasa tinggi sebanyak 300 W telah digunakan untuk pengubahsuaian permukaan bagi sampel bahan keluli karbon tinggi AISI H13, keluli karbon rendah AISI 1025 dan besi tuang. Rekabentuk eskperimen dengan faktorial penuh 3^3 hanya dijalankan untuk sampel keluli H13 dan besi tuang manakala ujian parameter awal telah dijalankan untuk keluli karbon rendah 1025. Terdapat tiga faktor kawalan yang terlibat dalam rekabentuk eksperimen iaitu kuasa puncak lasik, kekerapan nadi lasik dan kelajuan mengimbas. Untuk H13, kuasa puncak adalah 1.7 hingga 2.5 kW, kekerapan nadi antara 40 higga 60 Hz manakala kelajuan mengimbas antara 1000 hingga 1400 mm/min. Untuk besi tuang pula, kuasa puncak adalah 0.83 hingga 1.25 kW, kekerapan nadi antara 50 higga 70 Hz manakala kelajuan mengimbas antara 1000 hingga 1400 mm/min. Sampel permukaan keluli yang telah diubahsuai akan melalui pengukuran dari segi morfologi permukaan, kajian metalografi, kekasaran permukaan dan tahap kekerasan. Kajian morfologi melibatkan perubahan geometri permukaan keluli yang diubahsuai menggunakan lasik. Manakala kajian metalografi melibatkan kesan ketebalan lapisan yang telah diubahsuai, perubahan fokus lasik dan struktur saiz butiran keluli terhadap parameter. Perbezaan ciri-ciri lapisan keluli yang diubahsuai untuk semua jenis bahan turut dibentangkan dalam tesis ini. Analisis statistik telah dijalankan untuk keluli karbon tinggi AISI H13 dan besi tuang dengan menggunakan Response Surface Method (RSM) dimana ia meliputi analisis ANOVA dan pengoptimuman model. Kestabilan terma turut dijalankan untuk sampel keluli karbon tinggi H13 yang mempunyai kekerasan paling tinggi. Kajian tersebut penting bagi mengkaji had kekuatan keluli apabila dikenakan suhu yang tinggi. Ketebalan lapisan permukaan keluli yang telah diubahsuai dengan menggunakan lasik adalah antara 42 μm hingga 450 μm manakala tahap kekerasan permukaan keluli yang berjaya diperolehi adalah serendah 1.10 μm. Nilai maksima kekerasan keluli yang telah berjaya diperolehi adalah antara 1000 $HV_{0.1}$ sehingga 1427 $HV_{0.1}$. Analisis statistik pengoptimuman bagi keluli H13 dan besi tuang pada kekasaran permukaan minimum, maksimum kekerasan dan maksimum ketebalan lapisan diubah suai masing-masing telah menghasilkan 15 dan 26 solusi. Batasan suhu bagi lapisan yang diubah dalam aplikasi boleh di tentukan melalui ujian kestabilan termal.Kekerasan permukaan keluli yang diubahsuai terbukti sehingga 512.8 $HV_{0.1}$ apabila dipanaskan dengan suhu setinggi 800 ^oC. Penemuan kajian di dalam tesis ini penting untuk penambahbaikan sifat permukaan keluli untuk acuan besi separa pepejal dan pembangunan aplikasi penebat kehausan permukaan keluli.

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APPENDIX G

LIST OF PUBLICATIONS

Fauzun, F., Wahab, M. & Aqida, S. N. 2013. Laser Surface Modification of AISI 1025 Low Carbon Steel Using Pulsed Nd: YAG Laser for Enhance Surface Properties. *Key Engineering Materials*, **554**: 596-602.

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