EFFECT OF HIGH VELOCITY OXY-FUEL (HVOF) COATINGS ON FATIGUE BEHAVIOUR OF CARBON STEEL

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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ABSTRACT

Nowadays, the application of high velocity oxy-fuel (HVOF) spraying is widely used in various industries. This is due to its ability to improve the wear, erosion and corrosion resistance of components. However, by taking consideration of mechanical properties and fatigue behaviour into cognisance, the consequence of the HVOF thermal spraying coating on the components remain debatable. In this research, the main objectives are to obtain the mechanical properties, investigate the fatigue behaviour and observe the microstructure of the uncoated and coated carbon steel. The morphology, chemical composition and the phase of the specimen were characterized using an optical microscope (OM), scanning electron microscope (SEM), energy dispersive spectrometer (EDS) and x-ray diffraction (XRD). The microhardness of the specimen was tested with loads of 0.05 HV within dwell time of 10 s. Tensile test was carried out with a strain rate of 0.5 mm/min and a dog bone shaped specimen in accordance with ASTM-E8 standard. Fatigue test was performed under the stress ratio, R = -1 in accordance with ASTM-E466 by tension-compression cyclic loading (sine wave) with a frequency of 20 Hz. The results showed that the microhardness of the coated steel decreased by 40% and the yield strength of the coated steel decreased by 9.5% due to the increment of the substrate´s grain size resulting from the high HVOF flame temperature (2750 ˚C). The increment of coating thickness from 0.15 to 0.35 mm decreased the yield strength of the coated by 4.4% as due to the long-time exposure to high HVOF flame temperature. From the grit-blasting treatment, the embedment of the grit particles, cracks and notches on the substrate´s surface are the main reasons for the reduction of the tensile strength of the substrate by 9.1%. Similar behaviours are shown by the fatigue properties, as the HVOF coated steel showed a fatigue strength's reduction of 17% due to the increment of the substrate's grain size. These findings conclude that HVOF spraying process gives negative impact on the mechanical properties and fatigue properties.

ABSTRAK

Pada masa kini, penggunaan semburan oksigen-bahan api berkelajuan tinggi (HVOF) semakin meningkat dalam industri. Hal ini disebabkan oleh kemampuannya untuk meningkatkan ketahanan kehausan, ketahanan hakisan dan ketahanan kakisan pada sesuatu komponen. Walau bagaimanapun, penerimaan proses HVOF dalam industri turut bergantung pada prestasi mekanikal dan sifat kelesuan sesuatu komponen. Oleh yang demikian, penyelidikan ini dapat membantu dalam memperoleh sifat mekanikal, menyiasat kelakuan kelesuan dan memerhati mikrostruktur pada keluli dengan salutan dan keluli tanpa salutan. Perncirian morfologi, komposisi kimia, dan fasa spesimen boleh diperoleh menggunakan mikroskop optik (OM), mikroskop elektron pengimbas (SEM), penyebaran tenaga spektrum (EDS) dan pembelauan sinar-x (XRD). Mikrokekerasan spesimen diuji dengan muatan 0.05 HV dengan tempoh tinggal selama 10 s. Ujian tegangan dilakukan dengan spesimen berbentuk tulang anjing dan kelajuan regangan sebanyak 0.5 mm/min mengikut standard ASTM-E8. Ujian kelesuan pula dilakukan dengan nisbah tegangan sebanyak R = -1 dan pemuatan siklik tegangan-mampatan (gelombang sinus) di bawah frekuensi 20 Hz mengikut standard ASTM-E466. Hasil dari ujian menunjukkan penurunan mikrokekerasan sebanyak 40% dan penurunan kekuatan alah sebanyak 9.5%. Hal ini kerana suhu yang tinggi (2750 ˚C) daripada proses HVOF yang menyebabkan kenaikan saiz butiran pada substrat. Kekuatan alah keluli bersalut juga menurun sebanyak 4.4% selari dengan peningkatan ketebalan lapisan daripada 0.15 hingga 0.35 mm. Hal ini disebabkam oleh pendedahan yang terlalu lama dalam suhu yang tinggi. Rawatan peledakan pasir juga telah menyebabkan penurunan kekuatan tegangan sebanyak 9.1%. Hal ini kerana penanaman biji pasir, retakan dan lekukan di permukaan substrat. Keputusan yang sama juga diperolehi daripada ujian kelesuan, di mana proses HVOF telah menyebabkan pengurangan kekuatan kelesuan sebanyak 17%. Hal ini disebabkan oleh peningkatan saiz butiran pada substrat. Sebagai kesimpulan, proses HVOF memberi impak yang negatif kepada sifat mekanikal dan sifat kelesuan sesuatu komponen.

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LIST OF SYMBOLS AND ABBREVIATIONS

avg.	-	Average
A	-	Area
AISI	-	American Iron and Steel Institute
Al	-	Aluminium
Al-4Cu	-	Aluminium 4 wt.% copper
Al_2SiO_5	-	Aluminium (II) silicate (V), Coal slag
ASTM	-	American society for testing and materials
Co	-	Cobalt
CoCr	-	Cobalt chromium
Co_7W_6	-	Cobalt (VII) tungsten (VI)
Co-Cr-Si-W	-	Cobalt chromium silicon tungsten
Cu	-	Copper
Fe	-	Iron
Fe_3Al	-	Iron (III) aluminium
Fe-0.4C-18Mn	-	Iron 0.4 wt.% carbon 18 wt.% manganese
Fe-23Cr-8.5Ni	-	Iron 23 wt.% chromium 8.5 wt.% nickel
etc.	-	et cetera
et al.	-	and others
ε	-	Strain
E	-	Elastic modulus
EDS	-	Electron dispersive spectrometer
F_a	-	Load/Force amplitude
h_1	-	1st horizontal line
h_2	-	2nd horizontal line
HB	-	Hardness brinell
HSLA	-	High-strength low-alloy
HV	-	Hardness vickers

HVOF	-	High velocity oxy-fuel
K	-	Correction factor
K_f	-	Fatigue notch factor
K_s	-	Surface factor
ΔL	-	Total elongation
λ	-	Wavelength
max.	-	Maximum
min.	-	Minimum
Mn	-	Manganese
N_f	-	Number of cycles to failure
Ni	-	Nickel
NiW	-	Nickel tungsten
NiWCrSiFeB	-	Nickel tungsten chromium silicon iron boron, Colmonoy 88
Ni_5Al	-	Nickel (V) aluminium
σ	-	Stress
σ_a	-	Stress amplitude
σ_B	-	Breaking strength
σ_e	-	Fatigue limit
σ_f	-	Fatigue strength
σ_m	-	Mean stress
σ_{max}	-	Maximum stress
σ_{min}	-	Minimum stress
σ_u	-	Ultimate tensile strength
σ_y	-	Yield strength
$\Delta\sigma$	-	Stress range
OM	-	Optical microscope
P	-	Phosphorous
R	-	Stress ratio
$R_{p0.2}$	-	0.2% offset yield strength
S	-	Sulphur
S-N	-	Stress-life
SCM	-	Chromium molybdenum steel
SEM	-	Scanning electron microscope

Si	-	Silicon
SiC	-	Silicon carbide
Ti	-	Titanium
Ti-6AI-4V	-	Titanium 6 wt.% aluminium 4 wt.% vanadium
v_1	-	1st vertical line
v_2	-	2nd vertical line
W	-	Tungsten
WC	-	Tungsten carbide
W_2C	-	Tungsten (II) carbide
WC-Co	-	Tungsten carbide cobalt
WC-Co-Cr	-	Tungsten cobalt chromium
WC-CrC-Ni	-	Tungsten carbide chromium carbide nickel
WC-Ni	-	Tungsten carbide nickel
WC–10Co–4Cr	-	Tungsten carbide 10 wt.% cobalt 4 wt.% chromium
WC-10Ni	-	Tungsten carbide 10 wt.% nickel
WC-12Co	-	Tungsten carbide 12 wt.% cobalt
WC-17Co	-	Tungsten carbide 17 wt.% cobalt
$WC\text{-}20Cr_3C_2\text{-}7Ni$	-	Tungsten carbide 20 wt.% chromium (III) carbide (II) 7 wt.% nickel
XRD	-	X-ray diffraction
Y-TZP	-	Yttrium stabilized tetragonal zirconia
$Y_2O_3\text{-}ZrO_2$	-	Yttrium stabilized zirconia

LIST OF APPENDICES

LIST OF PUBLICATIONS

Journals:

(i) Fatigue Performance of Thermal Spray Coatings on Carbon Steel: A Review

(ii) Effects of High Velocity Oxy-Fuel Coatings on the Tensile Properties of S50C Steel

CHAPTER 1

INTRODUCTION

1.1 Research background

Recently, thermal spray coatings are widely applied to improve the component's surface properties such as wear resistance, corrosion resistance, erosion resistance etc. The thermal spray coating process involves heating a source to melt the powders in the shape of small droplets, which are then sprayed to the substrate at a high velocity. The three major categories of thermal spray coatings are flame spray, electric spray, and plasma spray [1].

High velocity oxy-fuel spraying (also known as HVOF) is a new development of thermal spray process which lies under the flame spray category. It has been extensively used to obtain good bond strength, higher density and less decarburization coatings. This is due to the lower flame temperature (3000 °C) and higher particle velocities (400 ms^{-1} - 1000 ms^{-1}) experienced by the powder particles as compared with other thermal spray techniques like vacuum/low-pressure plasma and atmospheric plasma with a temperature of around 12000 °C and velocities of 150 ms^{-1} - 600 ms^{-1} [2].

In addition, cemented tungsten carbide powder has been introduced to improve the performance of the coating using HVOF. This consists of hard carbide phase (WC) embedded in a ductile metallic matrix referred to the binder phase such as cobalt (Co) and nickel (Ni). For WC-Co based powder, the carbide phase provides high hardness and wear resistance, meanwhile, the cobalt-binder phase contributes to the toughness and strength [3]. WC-Co powder is well known for its superior abrasive and erosive wear resistance besides their remarkable mechanical properties such as high hardness, excellent high-temperature strength, good corrosion resistance, chemical and thermal stability during the high-temperature operations, hence, making WC-Co commercially

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