SURFACE MODIFICATION OF DUPLEX STAINLESS STEEL USING TIG TORCH AND NITRIDING PROCESSES FOR TRIBOLOGICAL APPLICATIONS

BY

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ABSTRACT

Duplex stainless steel (DSS) is widely used in petrochemical, waste incineration and gas turbine industries. However, DSS suffers from poor hardness and wear resistance that limits the applicability of the DSS for wider applications. Surface modification is required to improve the surface characteristics of DSS surface. The main objective of this study is to develop hard surface on DSS using TIG torch and nitriding processes. In TIG torch, the process was performed using different parameters such as silicon carbide (SiC) particle size of 20 µm - 100 µm, current of 80 - 100 A, voltage of 20 - 40 V, transverse speed of 1 -2 mm/s and argon flow rate of 15 -25 L/min. For nitriding, the experiments was conducted at different temperature of 400 ºC – 550 ºC, holding time of 4 - 16 hours and gas mixture ratio of 0.2 - 0.5 NH_3/N_2. The surface modified DSS was characterized using optical microscopy, scanning electron microscopy and x-ray diffraction. The hardness measurement was carried out using Vickers hardness tester based on ASTM E384, while wear behavior was assessed using ball-on-disc tribometer according to ASTM D6079. A design of experiment based on Taguchi method has been adopted to optimize the TIG torch and nitriding process parameters. The results show that hard surface DSS was successfully developed using TIG torch and nitriding processes. Characterization of the TIG melted layer DSS reveals the existence of new phases containing a dendritic structure, while nitrided layer DSS demonstrated the presence of expanded austenite. The surface hardness was achieved approximately 85 % higher than the DSS substrate with hardness value of 1700 Hv for TIG torch melting and 1598 Hv for nitriding. The wear rate of TIG melted and nitrided surface DSS was reduced by 70 % and 85 % compared to DSS substrate with value of 2.1 x 10^{-4} mm^3/Nm and 1.06 x 10^{-4} mm^3/Nm, respectively. Furthermore, the friction coefficient obtained 0.27 for TIG melted layer and 0.36 for nitrided layer DSS representing 50 % and 63 % better than DSS substrate, respectively. It was revealed that the worn surface showed very mild abrasive wear compared to substrate which demonstrated very severe wear with ploughing marks. The optimum TIG torch and nitriding process parameters have been identified using the Taguchi method. The optimum process parameters for TIG torch on surface hardness and friction coefficient were; current of 80 A, voltage of 20 V, transverse speed of 1.5 mm/s and argon flow rate of 25 L/min. Meanwhile, for wear rate, the optimum parameters were; 80 A, 30 V, 1.5 mm/s and 25 L/min. For nitriding, the optimum process parameters for hardness and friction coefficient were; temperature of 550ºC, holding time of 16 hours and gas mixture ratio of 0.3 NH_3/N_2, while for wear rate; 550ºC, 16 hours and 0.4 NH_3/N_2. Current was the most influencing parameter for the improvement of TIG torch melting, whereas, temperature and holding time for nitriding process. It was revealed that both processes are comparable and capable to produce hard surface layer on DSS with higher hardness and wear resistance properties which can be used for tribological and high temperature applications.

خلاصة البحث

يستخدم الفولاذ المزدوج المقاوم للصدأ (DSS) على نطاق واسع في الصناعات البتروكيماوية وحرق النفايات وتوربينات الغاز. ومع ذلك، يعاني DSS من صلابة ضعيفة ومقاومة التآكل والتي تحد من إمكانية تطبيق DSS على تطبيقات أوسع. هناك احتياج لتعديل السطح وهذا لتحسين الخصائص السطحية لسطح الDSS. الهدف الرئيسي من هذه الدراسة هو تصميم سطح صلب على DSS باستخدام مشعل TIG و عمليات النتردة (Nitriding processes). في مشعل TIG، تم تنفيذ العملية باستخدام متغيرات مختلفة مثل حجم جسيمات كربيد السيليكون (SiC) والذي يتراوح بين 20- 100 مايكرومتر، و تيار يتراوح بين 80- 100 أمبير، و جهد يتراوح بين 20-40 فولت، وسرعة عرضية تتراوح بين 1 -2 مم / ثانية، ومعدل تدفق أرجون يتراوح بين 15 -25 لتر/ دقيقة. بالنسبة للنتردة، أجريت التجارب على درجات حرارة مختلفة تتراوح بين 400 - 550 درجة مئوية، ومدة حجز بين 4-16 ساعة ونسبة مزيج للغاز من 0.2 - 0.5 N_2 /NH_3 . تم تمييز سطح الDSS المعدّل باستخدام المجهر الضوئي، والمسح المجهري الإلكتروني، وحيود الأشعة السينية. تم إجراء قياس الصلابة باستخدام جهاز اختبار الصلابة Vickers اعتمادًا على ASTM E384، بينما تم تقييم سلوك التآكل باستخدام مقياس احتكاك الكرة على القرص وفقًا لـ ASTM D6079. تم استخدام نظام Taguchi كتصميم للتجربة لتحسين متغيرات عملية مشعل TIG و النتردة. تظهر النتائج نجاح تطوير سطح صلب للDSS باستخدام مشعل TIG والنتردة. حيث أن توصيف طبقة الDSS الذائبة بواسطة الTIG تكشف عن وجود مراحل جديدة تحتوي على هيكل شُجيري (dendritic structure) ، في حين أن طبقة DSS المنترتة أظهرت وجود الأوستينيت الممتد. تم تحقيق صلابة السطح تقريبًا بنسبة 85٪ أعلى من ركيزة الDSS مع قيمة صلابة Hv 1700 في ذوبان شعلة TIG و1598 Hv في النتردة. وتم تخفيض معدل التآكل الخاص بسطح ال DSS المذاب بواسطة ال TIG والمنترد بنسبة 70 ٪ و85 ٪ مقارنة بركيزة الDSS التي تحمل نسبة $2.1x\ 10^{-4}$ مم مكعب / نانومتر و$1.06\ x\ 10^{-4}$ مم مكعب/ نيوتن متر، على التوالي. علاوة على ذلك، حصل عامل الاحتكاك على 0.27 للطبقة الذائبة بواسطة ال TIG و0.36 لطبقة DSS المنتردة وذلك يُمثل 50 ٪ و 63 ٪ نسبة أفضل من ركيزة الDSS، على التوالي. تم الكشف عن أن السطح المهترئ أظهر تآكل معتدل جدا مقارنة بالركيزة التي أظهرت تآكل شديد جدا مع علامات الحرث. تم تحديد المتغيرات المثلى شعلة الTIG وعملية النتردة العملية باستخدام طريقة Taguchi. وكانت متغيرات العملية المثلى لشعلة الTIG على صلابة السطح وعامل الاحتكاك كالتالي: تيار 80 أمبير، جهد 20 فولت، سرعة عرضية 1.5 مم / ثانية ومعدل تدفق أرجون 25 لتر / دقيقة. أما بالنسبة لمعدلات التآكل، كانت المتغيرات المثلى هي: 80 أمبير و 30 فولت و 1.5 مم/ثانية و 25 دقيقة/لتر. وبالنسبة للنتردة، كانت متغيرات العملية المثلى للصلادة وعامل الاحتكاك هي: درجة حرارة 550 مئوية، وحجز لمدة 16 ساعة ، ونسبة مزيج للغاز 0.3 N_2 /NH_3 ، في حين بالنسبة لمعدل التآكل فهو 550 درجة مئوية ، 16 ساعة و 0.4 N_2/ NH_3 .كان التيار أكثر المتغيرات تأثيرًا على تحسين ذوبان شعلة TIG، في حين أن درجة الحرارة و وقت الحجز كانا أكثر المتغيرات تأثيرًا في عملية النتردة. تم الكشف عن أن كلا العمليتان قابلتان للمقارنة وقادرتان على إنتاج طبقة سطحية صلبة على الDSS مع صلابة أفضل وخصائص مقاومة للتآكل والتي يمكن استخدامها لتطبيقات الاحتكاك والتطبيقات ذات درجة الحرارة المرتفعة.

APPROVAL PAGE

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Lailatul Harina Binti Paijan

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LIST OF ABBREVIATIONS

Å	Angstrom (unit for crystallite size)
α-Fe	Alpha ferrite
µm	Micrometer
γN	Expanded austenite
AFR	Argon flow rate
ASTM	American society for testing and materials
C	Carbon
CoF	Coefficient of friction
Cr	Chromium
CrC	Chromium carbide
CrN	Chromium nitride
CVD	Chemical vapor deposition
CrSi	Chromium silicide
DOE	Design of experiment
DSS	Duplex stainless steel
EDM	Electrical discharge machining
EDX	Energy dispersive X-ray
Fe	Iron
Fe-Cr	Iron chromium
FeSi	Iron silicide
Fe_3C	Iron carbide
Fe_3N	Iron nitride
FWHM	Full width half maximum
Hv	Vickers hardness (unit of micro-hardness)

JCPDS	Joint committee on powder diffraction standards
LTB	Larger the better
Mn	Manganese
Mo	Molybdenum
OA	Orthogonal array
OM	Optical microscopy
PVD	Physical vapor deposition
S	Sulphur
SEM	Scanning electron microscopy
Si	Silicon
SiC	Silicon carbide
STB	Smaller the better
S/N	Signal to noise
TIG	Tungsten inert gas
XRD	X-ray diffraction

CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND

Duplex stainless steel (DSS) consists of ferrite and austenite phases having good corrosion resistance, higher strength and ease of fabrication. The alloying elements are chromium, molybdenum, tungsten and nitrogen content that made this material resist to chloride pitting and crevice corrosion. DSS is extensively used in petrochemical, waste incineration, gas turbine industries, heavy constructions vehicle for hydraulic pump piston and transmission gear, cargo tanks for ships and trucks, air duct incineration for power generation and petro-chemical processing industry for pressure vessel, tanks piping and heat exchangers.

Although DSS is widely used in various applications including AISI Duplex-2205, the drawback of this material are hardness and wear problem which restricted the usage in most tribological applications. Due to this, in the past few years, a number of researchers have attempted to improve this limitation using tungsten inert gas (TIG) torch welding (Zou et al., 2014), laser cladding (Ghusoon et al., 2017), carburizing (Ahmad & Jauhari, 2012), plasma nitriding (Nagatsuka et al., 2010) and hybrid treatment of carburizing and nitriding (Adenan et al., 2014a). Most of the findings exhibited an improvement on the surface properties of this material. However, reports on surface modification of duplex stainless steels such as AISI Duplex-2205 treated by TIG torch with powder preplacement and nitriding processes are not available in literatures. Furthermore, most of the researches published in the literature were focused on the melting using laser glazing and nitriding using plasma process which is reported to increase wear and corrosion resistance significantly. However, these processes are