Materials and Design 100 (2016) 223–234

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Surface alloying of high-vanadium high-speed steel on ductile iron using plasma transferred arc technique: Microstructure and wear properties

H.T. Cao [a,b], X.P. Dong [a,*], Z. Pan [a], X.W. Wu [a], Q.W. Huang [a], Y.T. Pei [b,*]

[a] State Key Laboratory of Materials Processing and Die & Mould Technology, School of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
[b] Department of Advanced Production Engineering, Engineering and Technology Institute Groningen, Faculty of Mathematics and Natural Sciences, University of Groningen, Nijenborgh 4, 9747, AG, The Netherlands

ARTICLE INFO

Article history:
Received 3 November 2015
Received in revised form 21 March 2016
Accepted 22 March 2016
Available online 7 April 2016

Keywords:
Plasma transferred arc technique
Surface alloying
High-vanadium high-speed steel coating
Ductile iron
Microstructure
Wear properties

ABSTRACT

A high-vanadium high speed steel (HVHSS) alloying layer was synthesized from pre-placed powders (V-Cr-Ti-Mo) on ductile iron (DI) substrate using plasma transferred arc (PTA) technique. The PTA-alloyed layer, characterized by microhardness, optical microscopy, XRD, EDS enabled SEM, TEM and pin-on-disk tribometry, consists of three main regions: top alloyed zone (TAZ), intermediate remelted zone (IRZ), and heat affected zone (HAZ) of the DI substrate. A large number of globular carbides particles with size smaller than 5 μm form in the TAZ through in-situ reactions between the alloying elements and graphite in the molten pool. Further microstructural characterizations indicate that the carbides are primarily vanadium carbide (VC), confirming the formation of the HVHSS layer. The maximum microhardness of the PTA-alloyed sample occurring at the subsurface is 950 $HV_{0.2}$ which is 5 times that of the substrate. The HVHSS layer exhibits superior tribological performance in comparison to PTA-remelted DI, Mn13 steel and DI substrate. The enhanced performance is attributed to the formation of mixed hard-phases such as MC, M_7C_3, $M_{23}C_6$, martensite and grain refining through rapid solidification accompanying the PTA process.

1. Introduction

Ductile iron (DI) is widely used in a broad range of industrial applications such as machine tool beds, cams, valves, cylinder blocks, etc., due to its low production cost combined with favorable properties like machinability, excellent castability and comprehensive strength-toughness [1–3]. However, in severe service circumstances like those in mining and rolling sectors, the low hardness and poor wear resistance limit its further industrial applications. Moreover, bulk or conventional surface treatment like flame surface hardening is ineffective to strengthen ferrite-matrix ductile iron since there is insufficient pearlite that can be transformed into martensite [4]. Recently, hardfacings introduced by melting and alloying via high-energy beams (e.g. laser beam, electron beam) are new trends in surface strengthening of ductile iron [5–7]. Rapid solidification and self-quenching during desired local surface remelting result in metastable phases which further transform into cementite, ledeburite and martensite, forming a similar structure with the hardened white cast iron [8–10]. However, the low-hardness cementite dominates in the white cast iron with a blocky or continuously interdendritic network morphology, elucidating its role as stress concentrator favoring matrix cracking. Therefore surface alloying is considered as a more viable alternative because during the surface alloying process, the alloying powders dissolve into a melting pool to form hard, fine alloy-carbides acting as reinforcements to achieve favorable mechanical properties such as high hardness and good abrasion resistance [11].

High-speed steel (HSS) coating could be an ideal candidate for providing highly desired properties on a DI substrate because the HSS contains a variety of primary carbides rich in vanadium, chromium, tungsten and molybdenum, etc., which exhibits excellent comprehensive mechanical properties, highlighting its high resistance to wear, reliable toughness and hot hardness even at elevated temperatures [12–16]. For instance, Bourithis and Papadimitriou synthesized a M-type HSS coating on the surface of a plain steel by PTA technique [13]. However, the carbides were mainly a network of fishbone-shaped M_6C-type and plate-like M_2C-type carbides [17] that unfavorably grew around the grain boundaries instead of dispersive metal carbides (MC). V. Lazić et al. pointed out that carbides precipitated at the grain boundaries or arranged in a line significantly decrease resistance to

Table 1
Chemical composition of the ductile iron substrate (wt.%).

C	Si	S	Mn	P	Fe
3.7	2.7	0.03	0.3	0.04	Bal.

* Corresponding authors.
E-mail addresses: dongxp@mail.hust.edu.cn (X.P. Dong), y.pei@rug.nl (Y.T. Pei).

http://dx.doi.org/10.1016/j.matdes.2016.03.114

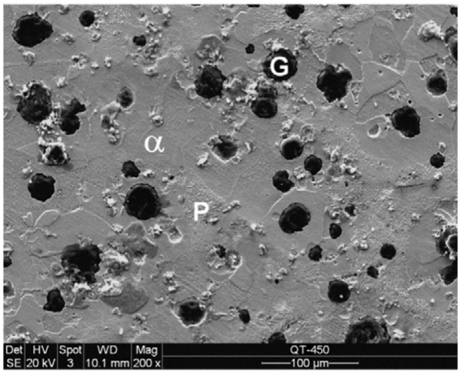

Fig. 1. SEM image of as-received DI, α: ferrite, G: graphite and P: pearlite.

Table 2
Chemical composition of the alloy powder (wt.%).

Element	V	Cr	Ti	Mo
Weight ratio	10	4	3	3

wear [18]. In general, alloy carbides provide higher hardness than cementite and martensite and hence greater resistance to wear. However, one should also note that the resistance to wear of carbides reinforced composites is not only determined by the hardness of carbides, but also by their size, distribution and shape. Large and irregularly-shaped carbides may be easily pulled out of the metal matrix or trigger stress fracture during the sliding tests [19]. Recently an as-cast high carbon

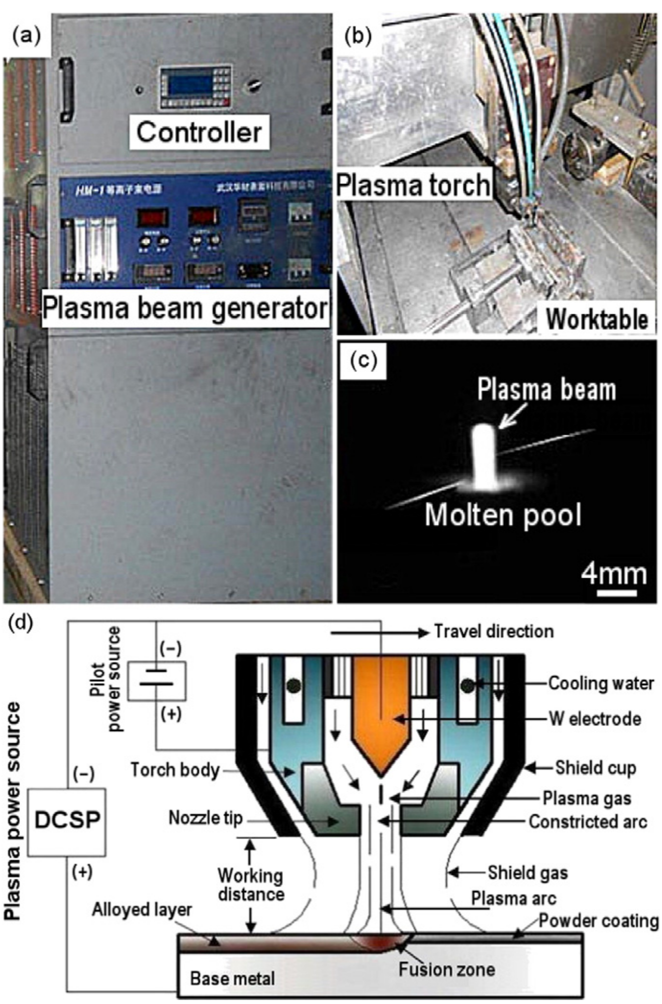

Fig. 2. PTA apparatus for surface alloying: (a) plasma generator, (b) plasma torch, (c) plasma beam and (d) diagram of the plasma torch [3].

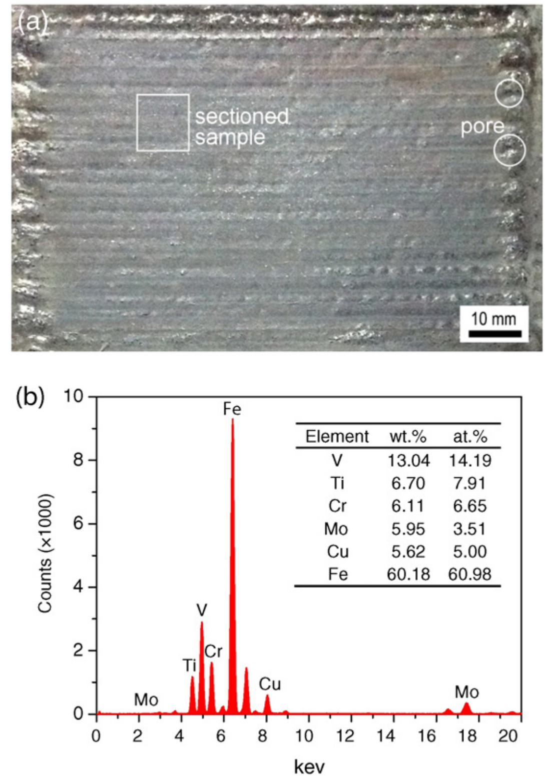

Fig. 3. (a) OM macroview and (b) XRF spectrum of the PTA-alloyed sample showing the alloying elements.

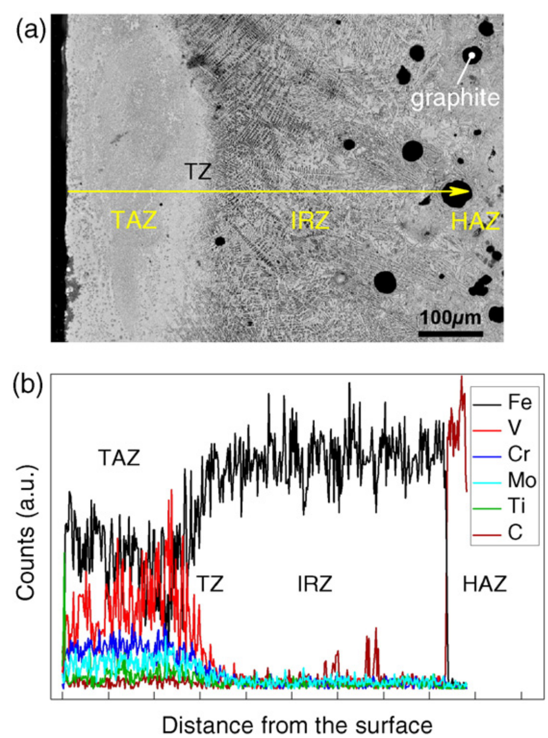

Fig. 4. (a) Cross-sectional overview of PTA-alloyed HVHSS layer on DI substrate showing three distinct zones: the top alloyed zone (TAZ), the intermediate remelted zone (IRZ) and the heat affected zone (HAZ); (b) EDS linear scan showing the element distribution along the depth direction as indicated by the arrow in panel (a).