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Plasma transferred arc surface modification of a low carbon steel

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Abstract The potential of Plasma Transferred Arc (PTA) hardfacing goes beyond the surface welding of superalloys. This work evaluated low carbon steel surface modification by PTA deposition of fine WCoC carbides, and mixtures of Fe powders and 5–35 wt% carbides. Characterization included visual inspection, optical and scanning electron microscopy, X-ray diffraction and microhardness profiles. PTA processing allowed for the dissolution of carbides confirmed by X-ray diffraction, leading to homogeneous microstructures. Microstructures varied from a Widmanstätten morphology to a typical dendritic solidification structure upon the WCoC content. Surface soundness depended on powder preparation and composition. Sound surfaces exhibiting hardness up to 700 Hv were obtained for the 35 wt% WCoC powder mixture.

Introduction

The potential of Plasma Transferred Arc (PTA) hardfacing goes beyond the surface welding of superalloys. In fact PTA processing should be described as a threefold technology as it allows for hardfacing through surface welding, surface alloying and surface modification. Surface welding of superalloys and other commercially available alloys has been widely studied and reported in the literature [1–7]. This process produces high quality, reliable coatings due to low dilution with the base metal, low distortion, and high powder efficiency as a result of precise deposition. Surface alloying procedures involve the mixture of powders of different elements and the subsequent PTA deposition to produce a specific alloy on the surface [8, 9]. These procedures allow for surface tailoring in order to protect components from specific service conditions. Surface modification, refers to adjustments made to the chemical composition of the surface. Solid solution strengthening can be accomplished by replacing argon with nitrogen as the plasma gas [10].

This work aims to produce surface modification of a low carbon steel AISI1020 through solid solution strengthening. For that purpose fine WCoC carbides were transferred through the plasma arc into the melt pool, in an attempt to melt the carbides within the plasma arc. As oppose to surface reinforcement using coarse carbides [11–13] to enhance abrasion resistance, by having the carbides bond with the matrix, the challenge in this study is to guarantee the complete melting of the alloy carbides in the steel and thus develop a harder, homogeneous surface.

Experimental procedures

Plasma Transferred Arc processing was used to modify the surface of a low carbon AISI 1020 steel. Due to the high melting temperature of the carbides, a fine powder size was selected. Surface processing was performed following two procedures: (1) the deposition of the 35 μm WCoC (W–17% Co–5% C) carbides; and (2) deposition of a mixture of WCoC carbides with iron powder, (particle sizes ranging from 90 to 150 μm), as a carrier to improve the powder flow. The following deposition conditions were tested to modify the AISI1020 steel surface:

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– Fine WCoC carbides and
– Mixture of 35 μm WCoC carbides with Fe powders. The powder mixtures contained 5 and 35 wt% WCoC carbides, respectively.

The powders were dried, and the mixtures were homogenized before deposition. The effect of processing parameters was evaluated for two deposition currents, 150 and 170 A, all other processing parameters being held constant. The processing parameters are listed in Table 1. There was no substrate pre-heating nor torch oscillation during deposition. The powder feed rate was held constant (by volume).

X-ray diffraction (XRD) analysis of the Fe–WCoC powder mixtures and processed surfaces was performed to evaluate phase changes associated with the deposition procedures. Vickers micro hardness profiles (with a 500 gf load) were obtained on the transverse cross-section of the deposits to assess the effect of processing parameters.

Surface characterization included microstructural analysis of the transverse section of specimens by optical and scanning electron microscopy (SEM) using the back scattered imaging mode. Semi-quantitative energy dispersive X-ray microanalysis (EDS) were performed on large areas, ~1 mm^2, in the SEM to identify chemical composition oscillations due to processing conditions.

Table 1 Processing parameters

Deposition current	150 and 170 A
Voltage	20.6 and 23 V
Travel speed	10 cm/min
Plasma gas	Argon; 2.0 L/min
Shield gas	Argon; 15.0 L/min
Powder feeding gas	Argon; 2.0 L/min

Results and discussions

General features

Powder preparation played an important role in the quality of the processed surfaces. The time interval between drying and deposition was a key factor, with powders mixtures deposited immediately after drying yielding the best results.

For the conditions tested, surfaces modified by the deposition of the fine WCoC carbides revealed a lack of soundness regardless of the processing parameters used. The presence of porosity and the non-uniform thickness of the deposits were attributed to the poor powder flow of the fine WCoC carbides. Theses surfaces were excluded from further characterization. The quality of the surfaces processed with the Fe–WCoC powder mixtures was a direct consequence of the drying and homogenization stages. Inadequate powder handling resulted in poor quality surfaces (Fig. 1).

For both deposition currents evaluated, the amount of carbide affected the geometry of the deposits, with the richer WCoC powder mixtures resulting in wider deposits. This behaviour was associated with the wettability reported for richer carbides melts [14].

Hardness

Hardness profiles measured on the transverse cross section of modified surfaces are presented in Fig. 2. Both powder mixtures resulted in an increase in surface hardness, and, as expected, the surfaces modified with the richer carbide mixture were harder. The relatively smooth profiles suggested that the modified surfaces were fairly uniform (i.e., a homogeneous distribution and/or melting of the fine WCoC carbides).

Deposition current did not influence the hardness following surface processing with the 5 wt% carbide mixtures, behaviour associated with the complete solubility

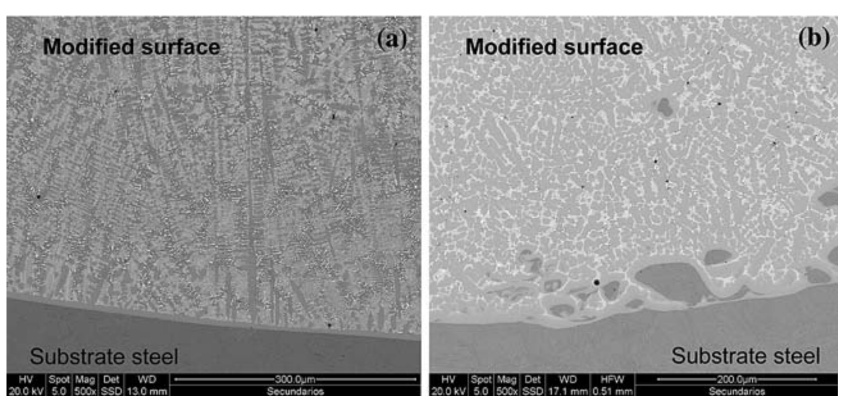

Fig. 1 Transverse cross-section of processed surfaces. (**a**) Smooth fusion line associated with a sound surface. (**b**) Irregular fusion line associated with poor quality deposits

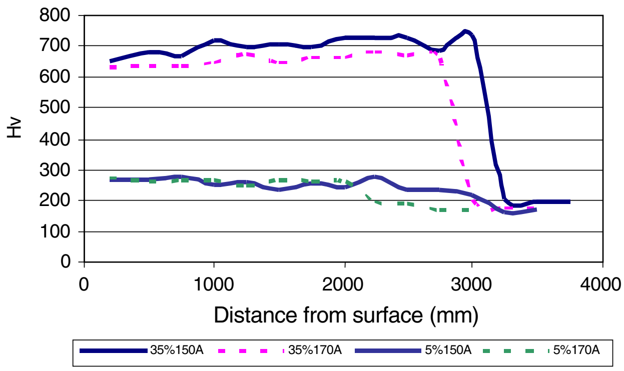

Fig. 2 Hardness profiles measured on the transverse cross-section for the two WCoC carbide contents

of the alloying elements. For the richer WCoC powder mixture, increasing the deposition current resulted in a lower surface hardness. This behaviour is related to a higher dilution of the (Fe + WCoC) powder mixture with the substrate steel on surfaces processed with a higher deposition current [1], as confirmed by the lower W content measured for these surfaces. The measured hardness of the surface modified using the 35 wt% carbide mixture is comparable to that expected on carburized components [16], with the advantage of not exposing the entire part to high temperature.

Microstructure

Homogeneous microstructures were observed on the transverse cross section of the deposits, suggesting the complete melting of the carbide particles. The as-deposited microstructure was determined by the amount of WCoC in the powder mixture. Surfaces modified by the deposition of Fe–5 wt% WCoC mixtures exhibited elongated α-ferrite grains. These are expected to develop in iron-base solid solution alloys exposed to rapid cooling such as that associated with the processing procedures used for the PTA

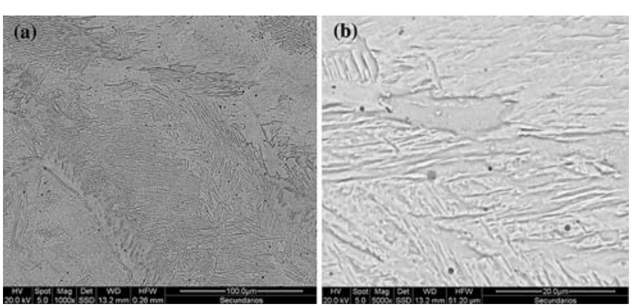

Fig. 3 Microstructure of the surfaces modified using the lower carbide content mixture: (**a**) general view and (**b**) Widmanstätten-like morphology

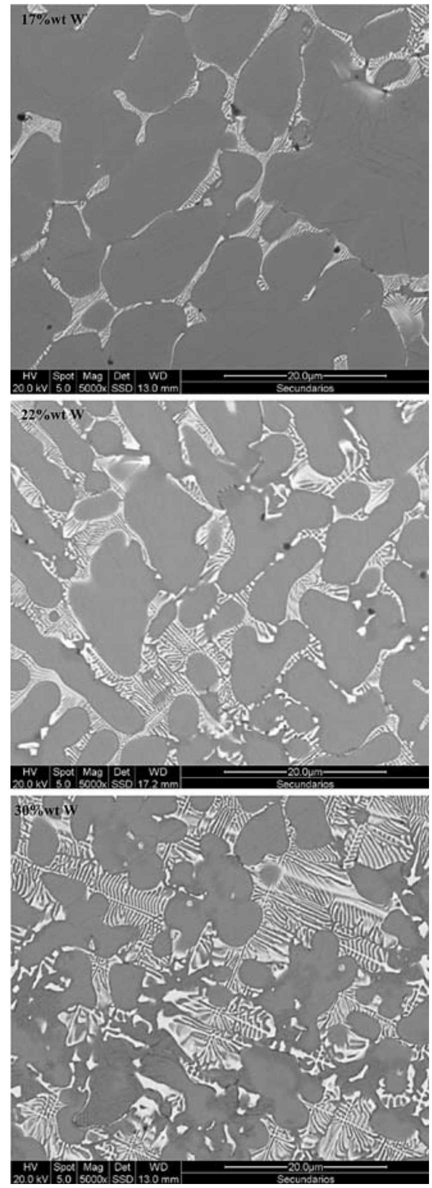

Fig. 4 Effect chemical composition fluctuations on the microstructure of 35% WCoC modified surfaces as a consequence of to dilution of the deposits with the AISI1020 substrate steel

process. Detailed characterization of the microstructure using scanning microscopy revealed a Widmanstätten-like morphology [14], which was clearly evident for the higher deposition current tested (170 A) (Fig. 3).

Deposition of the richer carbide powder mixtures resulted in a dendritic solidification structure (Fig. 4). As the solubility limit of C in iron is reached, carbides form, and an interdendritic Fe/carbide eutetic was observed. Processing parameters changed the solidification phase volume fraction distribution with larger interdendritic eutectic areas being observed for the richer W surface regions/lower deposition current, as confirmed by EDS

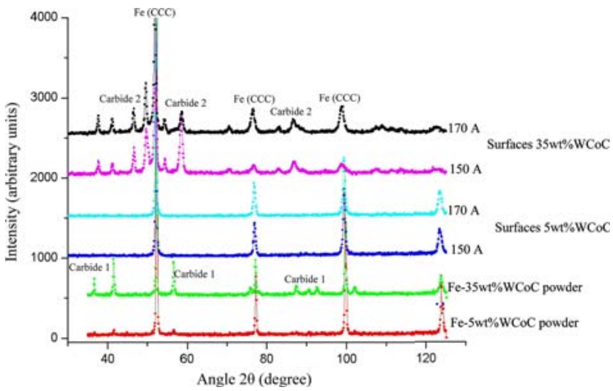

Fig. 5 X-Rays diffraction evaluation of the powder mixtures and final coatings

analysis. This trend is a consequence of the fluctuations in the surface chemical composition due to a more significant dilution of the deposited powder mixture with the low carbon steel substrate [15] as deposition current was increased.

The melting and dissolution of the fine WCoC particles during deposition was confirmed by X-ray diffraction analysis (Fig. 5). Powder mixtures contained the iron phase (BCC) and a tungsten carbide (carbide 1). After PTA surface processing, only the former remains unchanged. For Fe–5 wt% WCoC powder mixture deposits, only the iron phase was detectable, in agreement with solubility limits of tungsten (W), carbon (C) and cobalt (Co) on iron. For surfaces modified by the deposition of Fe–35 wt% WCoC mixtures, XRD analysis revealed that the original carbides (Carbide 1) present in the powder mixtures were replaced by a different carbide (Carbide 2) identified after processing, and was independent of deposition currents tested.

The observed behaviour is in agreement with steel processing literature [15] since the very low carbon surface (Fe–5 wt% WCoC) was able to retain W in solid solution. However, as the carbon content increased by melting the Fe–35 wt% WCoC powder mixture, carbides are expected to form and are consistent with the different features of Carbide 2 identified by X-ray diffraction after surface modification.

The results suggested that the procedures adopted were adequate for improving surface hardness, and are of particular relevance for applications to components that require surface hardening but can not be subjected to heat treatment.

Conclusions

– Plasma transferred arc processing provided a successful route to enhance surface properties by the deposition of mixtures of fine WCoC with iron powders.
– Surface soundness was dependent on the adequate powder handling.
– Surfaces modified by melting Fe–35 wt% WCoC powder mixtures exhibited a typical solidification structure with α ferrite dendrites and an interdendritric Fe/Carbide eutectic. Increasing dilution with the steel substrate altered phase distribution and surface hardness.
– Surfaces modified with Fe–5 wt% WCoC powder mixtures resulted in a slight increase hardness compared to the base steel which was associated with the presence of regions described as α ferrite with Widmanstätten-like morphology.

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