Surface & Coatings Technology 315 (2017) 519–529

Contents lists available at ScienceDirect

Surface & Coatings Technology

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

Oxidative wear behaviour of laser clad High Speed Steel thick deposits: Influence of sliding speed, carbide type and morphology

N. Hashemi [a], A. Mertens [a,*], H.-M. Montrieux [a], J.T. Tchuindjang [a], O. Dedry [a], R. Carrus [b], J. Lecomte-Beckers [a]

[a] University of Liege, Aerospace and Mechanical Engineering (AME), Metallic Materials Science Unit (MMS), Quartier Polytech 1, Allée de la Découverte 13A, B-4000 Liege, Belgium
[b] Sirris, Liege Science Park, Rue du Bois Saint Jean 12, B-4102 Seraing, Belgium

ARTICLE INFO

Article history:
Received 13 October 2016
Revised 9 February 2017
Accepted in revised form 27 February 2017
Available online 28 February 2017

Keywords:
Additive manufacturing
Laser cladding
High speed steel
Oxidative wear
Abrasive wear
Microstructural characterization

ABSTRACT

The oxidative wear behaviour of four different High Speed Steel (HSS) thick coatings (one cast material and three laser clad deposits with varying Mo, V and W contents) was investigated using a pin-on-disc tribometer at two different sliding speeds of 10 cm/s and 50 cm/s. Microstructural characterization (before and after the wear tests) was carried out by SEM and wear debris was analysed by XRD. For all four materials, the oxide layer was formed of hard and brittle haematite-type α-Fe_2O_3, prone to break and release debris that acted as a third body, thus increasing sample wear. The laser clad HSS materials exhibited a higher wear resistance than their conventional cast counterpart, thanks to their finer microstructures. In particular, the coarser MC and M_2C carbides present in the cast material were sensitive to cracking during the wear tests, releasing debris that contributed to increased third body abrasion together with oxide fragments. A detailed comparison of the wear behaviour of the three laser clad deposits, in correlation with their different microstructures, further demonstrated that harder V-rich MC carbides offered better wear resistance compared to the softer W-rich M_2C carbides. The morphology of the carbides also played a role in determining the wear resistance at the higher sliding speed of 50 cm/s. Clover-shaped primary MC carbides resisted wear better than angular ones due to their better geometric anchoring. Similarly, the geometric anchoring of eutectic M_2C carbides, forming a quasi-continuous network at the grain boundaries of the matrix, proved beneficial at higher sliding speed.

1. Introduction

Thick High Speed Steel (HSS) deposits are widely used in a great variety of applications including high speed machining and cutting operations, hot stamping, moulding and hot strip mills. These alloys belong to the complex Fe-Cr-C-X system, where X is a strong carbide-forming element such as V, Nb, Mo or W [1–4]. Thanks to their carefully tailored microstructure, containing very hard carbides located at grain boundaries in a matrix composed of martensite or bainite, HSS can withstand severe mechanical and physico-chemical stresses in service. Carbides in HSS typically include V-rich MC, Mo and W-rich M_2C, Cr-rich M_7C_3 or M_3C. These carbides can be of various types, i.e. primary, eutectic, and secondary carbides. Primary carbides precipitate before or during the solidification of the matrix, eutectic carbides form during solidification, while secondary carbides precipitate in the fully solid state. Primary carbides precipitate directly from the liquid phase inside the dendrites or cells before the eutectic solidification. They are larger than the eutectic carbides. Eutectic carbides precipitate from the residual liquid in the intercellular space at the end of the solidification process, and they form an almost continuous network. The exact nature and composition of solidification carbides depend on both the alloy's chemical composition and the cooling rate. Secondary carbides are very fine precipitates appearing either during the cooling stage of the manufacturing process, or during post-processing thermal treatments [2,5–8].

High speed steels obtained from conventional casting have received great attention so far. Their typical microstructures are composed of a quasi-continuous network of coarse grain boundary carbides with grain size ranging from 20 to 200 µm. In recent years, laser cladding has also received significant attention. Indeed, the very high cooling rates of 10^3 to 10^7 °C/s typical of this technique generate ultrafine microstructures, potentially giving rise to improved wear resistance [9–14]. Practically, laser cladding consists in covering a substrate with a deposit of a different nature. In this technique, a powder or a mixture of powders is melted while passing through a laser beam. The melted powder particles are deposited on the substrate, and in so doing, a thin layer of the substrate is also melted due to the thermal energy brought by the deposited particles. The beam energy must be sufficient to produce a cladding layer of high quality but not too high in order to avoid excessive dilution of the deposit into the substrate [15–20].

Earlier works on the laser cladding of tool steels focused more particularly on low alloyed grades and/or on relatively thin deposits [8,18,19,

---

* Corresponding author.
E-mail address: anne.mertens@ulg.ac.be (A. Mertens).

http://dx.doi.org/10.1016/j.surfcoat.2017.02.071

Table 1
Chemical composition of the investigated materials (wt%).

HSS material	C	Mn	Cr	Mo	V	W	Ni	Si
LC A	2.47	0.48	5.30	1.38	9.46	0.18	–	0.9
LC B	1.35	0.34	4.30	4.64	4.10	5.6	0.9	0.33
LC C (60% B + 40% A)	1.80	0.43	4.70	3.34	6.24	3.43	0.54	0.56
Cast	1.7–2.0	0.7–1.0	3.5–5.0	5.0–7.5	4.0–6.0	–	1.0–1.5	0.3–0.7

21–25]. Heat often tends to accumulate in thick laser clad deposits due to the fairly high laser power of 1 to 2 kW used in laser cladding, and to the fact that convection and radiation dominate the thermal transfers during cladding [26–28]. The heat accumulation may in turn result in large-scale microstructural heterogeneities over the whole height of the deposit [27,29,30]. Yet, only a few studies have investigated thick laser clad deposits, with thickness comparable to the conventional HSS coatings used, e.g., in cutting tools or hot strip mills [20,31].

Studies investigating specifically the influence of the microstructure of HSS alloys on wear behaviour are also still scarce [23,32–38]. Notable exceptions are the works by Wang et al. [25] and Tuominen et al. [39] on the resistance of high alloyed laser clad HSS materials with respect to abrasive wear. These investigations focused strictly on thin deposits, i.e. with a thickness of 1 to 2 mm that remains close to the dilution zone between the coating and substrate.

In the present work, a conventional cast thick HSS coating and three thick laser clad HSS deposits with different compositions have been investigated, with the aim of studying the influence of the microstructure on the oxidative wear behaviour. A commercial powder with a chemical composition matching that of the cast reference material could not be found. Three HSS powders with different contents of the carbide-forming elements V, Mo and W were thus used in order to approach the composition and carbide types of the cast reference material while varying the morphologies, sizes and amounts of these carbides. The upper layers of sound thick deposits with a thickness of 20–25 mm were used for the wear tests in order to avoid any influence of the dilution zone between the deposit and the substrate and to obtain results representative of the behaviour of thick deposits. Wear tests were carried out using a pin-on-disc tribometer, and the sliding speed was varied in order to reach a deeper understanding of the effect of the different types and morphologies of carbides.

2. Materials and experimental procedure

2.1. Materials

Four HSS compositions from the Fe-Cr-C-system with varying Mo, V and W additions were studied in this investigation (Table 1). One of the materials considered as reference was obtained by conventional casting and the others were produced by the additive manufacturing technique known as laser cladding (LC). In the latter case, three commercial HSS powders A, B, and C that are mixtures of 60% B and 40% A, were used as raw materials. These powders were chosen in order to approach the chemical composition of the cast material, while varying to some extent the carbides types and morphologies.

A 5-axis Irepa Laser Cladding system with an Nd-YAG laser source having a maximum power of 2000 W was used to make deposits of 30 to 35 mm side length and 20 to 25 mm height on a low alloyed steel substrate (Fig. 1). The cladding powder was injected into the laser beam by an inert gas flow and directed towards the substrate at an angle of 38–45°. The laser spot had a top-hat energy distribution with a diameter of 1400 μm, and the laser power was set in the range of 55 to 65% of the maximum power. The substrate was preheated in an external furnace in order to avoid cracking of the deposit, and its temperature was registered by a thermocouple at a value of 400 °C immediately before the start of deposition.

After fabrication, all samples (laser clad HSS and conventionally cast material) were tempered twice at 520 °C for 5 h, and then air-cooled, in order to promote the formation of secondary carbides during the isothermal hold, eliminate the residual austenite, as confirmed by X-ray diffraction, and increase the material's homogeneity.

2.2. Characterization

As mentioned earlier, the microstructure of thick laser clad deposits may vary as a function of the position within the deposit [27,29,30]. However, this microstructural variation is not in the scope of the present study, and all samples were taken at a constant depth within the deposits. Practically, square specimens of 30 mm side length and 5 mm thickness were extracted by means of electrodischarge machining at 2 mm of the material's free surface.

The microstructures of the laser clad and cast materials were characterized by scanning electron microscopy (SEM) using a PHILIPS XL 30 FEG-ESEM equipped with back-scattered electron (BSE), secondary electron (SE) and electron backscatter diffraction (EBSD) detectors, and with an energy dispersive X-ray spectrometer (EDS). In particular, EBSD was used in combination with EDS to identify the different types of carbides. Carbides quantification was carried out on mirror polished laser clad deposits using ImageJ software, and the grain size was measured using the intercepts method.

The hardness of the heat-treated specimens was obtained by Vickers hardness tests with a load of 20 kg on a universal EMCO MC10 device. Ten measurements were made for each specimen. The surface of the specimens was ground to prepare them for the wear tests. Wear tests were performed at room temperature and without lubricant on a CSM high temperature pin-on-disc tribometer (Fig. 2). The HSS materials

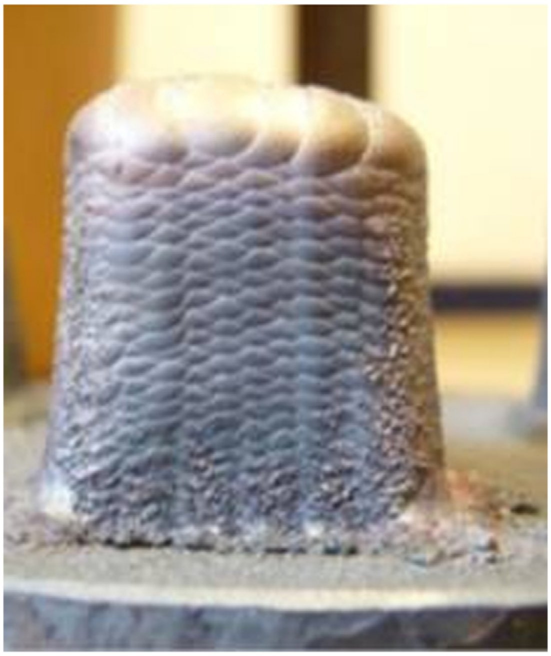

Fig. 1. Overview of a laser clad deposit.