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Microstructural and microchemical characterization of Ni-Ta-Al-Cr-C coating layer on austenitic stainless steel AISI 310

K. Wieczerzak [a,*], P. Bala [a,b], M. Stepien [b], G. Cios [b]

[a] AGH University of Science and Technology, Faculty of Metals Engineering and Industrial Computer Science, Al. A. Mickiewicza 30, 30-059 Kraków, Poland
[b] AGH University of Science and Technology, Academic Centre for Materials and Nanotechnology, Al. A. Mickiewicza 30, 30-059 Kraków, Poland

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ABSTRACT

Microstructural and microchemical characterization of Ni-Ta-Al-Cr-C coating layer, deposited by Gas Tungsten Arc Welding (GTAW) method on AISI 310 is presented. The layer was characterized by X-ray diffraction (XRD), light microscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM) and hardness measurements. Results obtained by XRD and TEM show that the coating layer consists of a γ-nickel matrix strengthened by the γ'-$Ni_3(Al,Ta)$ phase, MC and M_7C_3 carbides (of tantalum-and chromium-rich type, respectively). Growth mechanism, which depends on the cooling rate determines morphology of eutectic carbides. For slow growth rate MC carbides tend to be blocky, while for greater growth rate they exhibit a tendency to form more developed shapes. M_7C_3 carbides have a polygonal and reticulated plate morphology with different sizes. The γ'-$Ni_3(Al,Ta)$ phase has a spherical shape with few nanometers in diameter. The average hardness of the AISI 310 substrate is 174 ± 5 HV1, while the hardness of Ni-Ta-Al-Cr-C coating layer is 359 ± 31 HV1.

1. Introduction

Industrial practice shows that materials intended for critical parts, in many cases, should have very good combination of mechanical and physicochemical properties. Nevertheless, it often happens that a material characterized by attractive properties has a weak point, which makes necessary modifications to improve its usability. A good example is austenitic stainless steels, which inter alia, have been chosen as the main structural material for Indian Prototype Fast Breeder Reactor (PFBR) with liquid sodium as the cooling medium for transferring the heat from the reactor to the steam generators [1–3]. Some of the components in contact with liquid sodium are exposed to continuously damage the protective oxide layer (liquid sodium has tendency to remove the oxide film), mutual displacement and relatively high temperature (approx. 550 °C) [3]. As is known, austenitic stainless steels have poor wear resistance during sliding and show a clear tendency to galling and seizing. These phenomena are the cause of their high wear rates. Due to the possibility of strain-induced martensitic transformation in metastable austenitic grades such as AISI 304 and 316, friction conditions between materials, when at least one is made of these steels, may vary within a wide range. Martensite α' is hard enough to abrade tool steels [4]. It should be noted that the classical (during quenching) and strain-induced martensitic transformations do not occur in grades having a stable austenitic structure, e.g. AISI 310 [4–7].

In order to reduce adhesive wear and keep a high corrosion resistance of austenitic stainless steels, a number of methods have been developed to modify the surface layer, i.e. low temperature nitriding [8–11], duplex technique, which involves a combination of plasma nitriding and physical vapor deposition of ceramic coatings [12,13], and low temperature carburizing [11,14–16].

Another approach to improve the usability of austenitic stainless steels is to use hardfacing layers. Hardfacing of the mating surface has been widely used in austenitic stainless steel components of water-cooled and liquid sodium-cooled reactors to prevent galling and self-welding [1–3,17]. In order to increase, for example, the life of components of the Indian PFBR, the decision was to replace the traditionally used cobalt based alloy (e.g. Stellite 6) with nickel based hardfacing alloy RNiCr-B (Colmonoy-5) [2]. Analysis presented by Bhaduri et al. [1] has shown that the decrease in the hardness of the alloy RNiCr-B for 40 years of reactor operation should be less than of Stellite 6.

Generally, weld cladding of these alloys can be performed by arc welding processes (GTAW, GMAW, FCAW, SAW), solid state welding processes (explosion cladding or roll cladding) or vacuum brazing [18]. In recent years, sophisticated deposition methods have been developed, i.e. Plasma Transferred Arc Welding (PTAW) [19,20] and laser hardfacing [21,22]. The main advantages of these methods are lower microchemical redistribution in the deposit, very good bonding with the substrate and ability to give defect-free deposits.

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[*] Corresponding author.
E-mail address: kwiecz@agh.edu.pl (K. Wieczerzak).

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Table 1
Chemical composition of AISI 310 substrate (wt.%).

	C	Si	Mn	Cr	Ni	Mo	Nb	V	Fe
AISI 310	0.05	0.6	1.7	24.5	19.5	0.1	0.04	0.15	bal.

Table 2
Chemical composition of Ni-Ta-Al-Cr-C filler metal (wt.%).

	C	Cr	Ta	Al	Zr	Ni
Ni-Ta-Al-Cr-C	0.83	19.4	6.1	2.8	0.2	bal.

Table 3
GTAW parameters.

Parameter	Value
Electrode	
Type	W-1.5%La_2O_3
Diameter	2,4 mm
Angle	45°
Current	approx. 90 A, DC-
Voltage	7 V
Travel speed	approx. 30 mm/min
Nozzle	No. 8 with gas lens
Protective gas	
Type	Argon
Flow	12 l/min

Nickel based alloys strengthened by chromium carbides ($Cr_{23}C_6$, Cr_7C_3 and Cr_2C_3) and/or in many cases, the MC-type carbides (M = Nb, Zr, Ta, Hf) are well known in the literature. They have been extensively studied and developed recently, due to the attractive combination of mechanical and physicochemical properties, i.e. compressive strength, room and high temperature wear resistance, creep strength, oxidation and corrosion resistance, [23–31].

Ni-Ta-Al-Cr-C alloy was designed by Bała [25,26] over the period 2010–2012 and has been dedicated for use at high temperatures, in a chemically aggressive environment and under harsh wear conditions. Highly attractive properties of the Ni-Ta-Al-Cr-C alloy arise from a suitably designed matrix, high volume fraction of γ' phase and primary MC and M_7C_3 eutecticcarbides.

In the present work microstructural and microchemical analysis of Ni-Ta-Al-Cr-C coating layer deposited by Gas Tungsten Arc Welding (GTAW) method on AISI 310 substrate was performed.

2. Experimental

The substrate was austenitic stainless steel AISI 310 plate of size 80 × 80 × 15 mm, grinded and cleaned before welding. Its chemical composition was determined in cross-section by optical emission spectrometer Foundry-Master (WAS) and is summarized in Table 1. Alloy with high carbon content from Ni-Ta-Al-Cr system was used as filler metal in the form of a rod with square cross-section (a = 2 mm). Rods were prepared from the as-cast alloy using electrical discharge machining (EDM).The nominal chemical composition of the filler metal is given in Table 2. The carbon content was measured using the LECO CS-125 analyzer. Due to the form of filler metal, the coating layer was made manually by the GTAW process according to the diagram presented in Fig. 1. The welding was performed by a qualified welder. The GTAW process was chosen because of its high popularity and flexibility in manufacturing of hardfacing layers. Cross welding passes and reverse directions were used in order to obtain an appropriate clad geometry. The sample after welding of each pass was cooled for approx. 15 min in the air. The process was carried out using a Lincoln Electric INVERTEC 300TPX welding device. The process parameters were selected experimentally and are summarized in Table 3.

Identification of phases in the coating layer was performed on the cross section to first pass direction (Fig. 1, Sample A) on a Panalytical Empyrean diffractometer using Co Kα1 radiation (λ = 1.78901 Å). During XRD analysis, which was performed on the cross section to first pass direction (Fig. 1, sample A), AISI 310 substrate was masked using the lead foil. The sample phases were identified using XRD data in the 2θ range from 40 to 120° obtained under condition: voltage of 40 kV, current of 40 mA, step size of 0.013° and the collection time at each step of 8.3 s. For the measurements a Göbel Mirror was used.

Microstructures were examined on Nikon LV150N light microscope and FEI VERSA 3D scanning electron microscope (SEM), equipped with the Apollo XP SDD energy dispersive spectroscopy (EDS) detector. To analyse chemical distribution in the coating layer and eutectics, X-ray mapping, line scan and point analysis were performed on polished samples. For measurements,

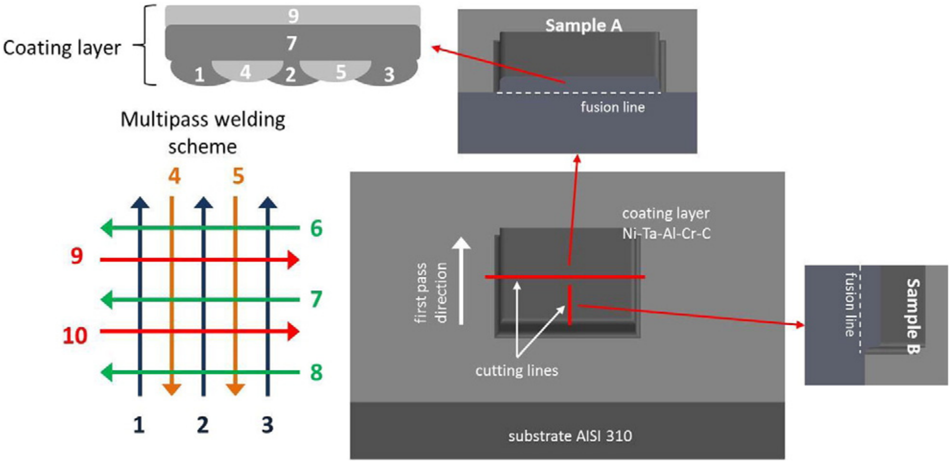

Fig. 1. Schematic diagram of hardfacing welding and methodology of sample preparation.