SiC and TiC Stainless Steel Based Metal Matrix Composites

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Stainless steel Metal Matrix Composites with SiC and TiC content, particularly applicable for high wear resistant applications, are to be discussed in the present paper: Metal composite materials (including composites with metal matrix - Metal-matrix composites /MMCs/) with carbide containing mixture on the surface layer are particularly suited in the chemical industry. They are superior with their improved strength, high modulus of elasticity and high wear resistance compared to conventional metal alloys.

The micro hardness, wear resistance and roughness characteristics of metallic composite materials with SiC and TiC carbides are investigated in order to develop a method and to get control of the mechanism of formation of stable multiphase systems.

Key words*: carbides, chemical synthesis, ceramics, fractal materials, metal-matrix composites*

INTRODUCTION

The receiving of new composite materials providing good strength characteristics as well as increased wear and surface corrosion resistance to metals and metal alloys is particularly relevant nowadays. In the chemical industry can be found a variety of challenging tribological situations which can be realized by development of protective wear-resistant coatings with advanced properties. [1-6]

A new approach to formation of surface metal composites based on silicon carbide and titanium carbide using an overlaying technology is proposed. Stainless steel matrix base materials are used for the preparation of samples namely commonly used ferritic, austenitic and super austenitic grades. By means of conventional surfacing with laser technique may be achieved layers of thicknesses between 1-5 mm.

The coatings were produced by injection of powder blend into the zone of laser beam action. The resulting materials are with promising characteristics for application in harsh abrasive conditions.

The method of laser cladding with powder injection for coating deposition has the following particular advantages: process flexibility (wide range of controllable parameters), excellent adhesion to a substrate, low coating porosity, local action of the laser beam, free-directional cladding, protection from the ambient atmosphere, relatively small heat affected zone. This method allows to obtain local coating deposition, line width in the range of 1.5-3 mm. It is possible to deposite protective coating exactly on desired area exposed to severe wear conditions. Also due to the possibility to mix different components the coating is produced with derived composition “in situ”.

The purpose of this research is to investigate the mechanism of formation of stable multiphase systems and suggest a technology for obtaining composites with preset properties.

METHODS AND EXPERIMENT

Initial Data

To meet the requirements of the industry [6] two types of coating structures are proposed: (i) a single layered of directly mixing the carbides in the base metal with samples of SiC over X5CrNi18-10 resulting in a structure of characteristic order for defining the depth of the metal matrix composite achieved and the particles distribution in the stainless steel (Fig. 1) and (ii) a metal matrix composite (MMC) produced from the ferritic, austenitic and super austenitic grades with simultaneous injection of TiC and gas-atomised Co-based alloy powders during laser cladding (Fig. 2).

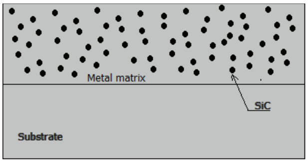


Fig. 1 Stainless steel based MMC

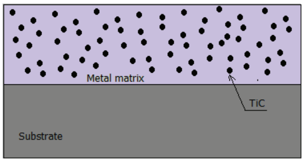


Fig.2 Traditional MMC with inclusions of TiC

The selected ferritic stainless steels are X2CrTi12 according to EN 10088-4:2009, the austenitic X5CrNi18-10 and the superaustenitic X1NiCrMoCuN20-18-7 are being subjected to TiC overlaying of single pass of a thickness of 1.5 mm. The chemical composition of the base metal is given in Table 1. There is a mixing layer of the base material and the matrix material of thickness not more than 10 μm. For the case of the SiC – stainless steel MMC there is observed the mixing only of the carbides and the solidified base metal.

Table 1 Chemical composition of the stainless steel bases

% Contents in	C	Si	Mn	P	S	Cr	Ni	Ti	N	Fe
X2CrTi12	0.03	1.00	1.00	0.040	0.015	12.30		0.64	0.025	rest
X5CrNi18-10	0.07	1.00	2.00	0.045	0.015	18.50	9.00	-	-	rest
X1NiCrMoCuN20-18-7	0.01	0.45	0.35	0.022	0.001	19.93	17.85	-	0.210	rest

Methods

Measurement of structure – micro and macro structure - the study of microstructure is performed for metallographic samples etched for the ferritic and austenitic grade by a mixture of 10 ml HNO_3, 20 ml of HCl and 30 ml H_2O. The samples are being held in the solution for 15 min then polished. The microstructures are viewed by microscope Axiovert 200MAT and Axiovision camera for recording.

Measurement of hardness - the study of the mechanical properties of materials in the range of a few micrometers are performed following the requirements for Instrumented indentation test for hardness and materials parameters according to БДС EN ISO 6507-1 with Durascan 70, working with load of 1 kN and allowing measurement with maximum sensitivity of samples with dimensions in the millimetre range area.

Resistance to abrasion measurement – SAR measured with Miller tester according to ASTM G75-01 for the abrasive response of the TiC composite which gives the relevant values for the approved properties compared to the general stainless steel characteristics in abrasive conditions.

Rroughness measurement - according surface quality requirements as per БДС EN ISO 1302:2003 performed by the portable Mitutoyo SJ-201P roughness instrument.

Experiment

The process of coating deposition consists of the following stages: powder preparation, delivery into the zone of the laser beam and coating depositioning. [7] A powder mixture of Cr 17.5, Mo 28, Si 3.4, and rest Co with TiC (purity 99.9 pct) with a mesh size of -100/+325 (particle diameters between 45 and 150 μm and volumetric ratio between the two components of 3:1) was used in order to produce a hard, composite coating on three stainless steel substrates, using the laser overlaying technique. [10] For the purpose of obtaining SiC coating only SiC powder was mixed in the melted base metal structure. [9, 11]. The powder mixture was introduced into the shielding gas of the laser Rofin Sinar DY22 equipment providing a flow of defined quantity into the melting pool. The parameters used were according to Table 2.

Samples are produced after laser cladding of the base material with powder feeder (carrying gas is argon). In the case with SiC the large amounts of carbides present in the microstructures can be described as composites with large and extremely hard carbides in a softer body centered-cubic (bcc) Cr-Fe alloy matrix in the case of the ferritic steel. [9] For the TiC due to the face centered (fcc) lattice of the austenite is experienced increased hardness.

Experimental set-up and procedure The schematic representation of the preparation process of the metal composites is presented in Figure 2. The application was laser assisted with forced powder mixture. The samples were with starting thicknesses 1 mm for the X5CrNi18-10 and 2 mm for the X1NiCrMoCuN20-18-7. Using the technique of *in situ* formation avoids complex operations when combining the individual components, which is a typical disadvantage in obtaining composite materials, such samples are prepared with only one operation from the starting melt chemically defined. Dendrite formation is inhibited by the absence of convection in the crystallizing melt. Due to the zone melting the obtained samples are with a small section. In this case 1.5 to 2 mm width and length limited to 20 mm.

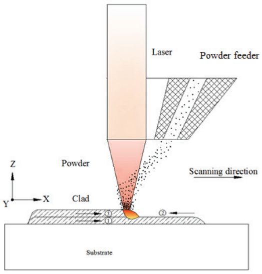


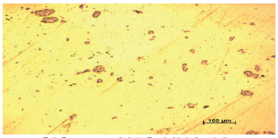
Fig. 2 Experimental laser setup for production of metal matrix composite

Table 2 Cladding parameters

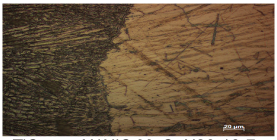
parameter / thickness	2 mm	1 mm
Welding power	2100-1800 W	1100-1300 W
Straight line welding speed	25 mm/s	25 mm/s
Shot distance	120 mm	120 mm
Focus setting	-1	-1
Gas backing	no	no
Welding position	PA	PA
Focal lens	200	200
Gas protection in coaxial nozzle	Ar 100%	Ar 100%
Flow rate of gas and powder	4 l/min	4 l/min
Distance between lines	2,5 mm	3 mm

Analysis of structure

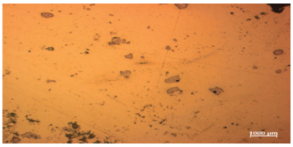
On figure 3 are shown the observed intermetallic carbides which had formed on the chromium basis. They are making the composite harder and are increasing the plasticity in a defined direction [9].



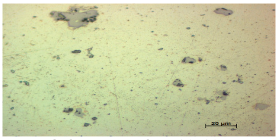
SiC over X5CrNi18-10



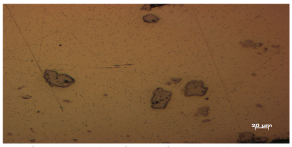
TiC over X1NiCrMoCuN20-18-7



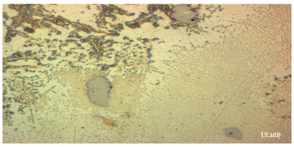
TiC over X5CrNi18-10



SiC over X5CrNi18-10



TiC over X1NiCrMoCuN20-18-7



TiC over X5CrNi18-10

Fig. 3 Micrographs of the microstructures formed as a reinforcing phase in SS substrate

Hardness

The basic hardness values of the stainless steels are compared with the ones achieved after the surface cladding of SiC and TiC. For the layers of SiC is achieved a Vickers hardness of 2600 only over the SiC hardfaced the austenitic steel whereas for the TiC the values for the ferritic and austenitic steels locally are in the range of 3200.

Wear analysis

A standard slurry abrasively test was run according to ASTM G75-01 to determine the SAR /slurry abrasion response/. The solid-fluid-mixture of distilled water and 0.045-0.075 mm particles of alumina powder (99.7% Al_2O_3, 0.2% Na_2O, 0.02% Fe_2O_3, 0.02 % SiO_2) in the slurry abrasion process via simulation of oscillating movement is used to determine the test samples material resistance. Two coated samples of X5CrNi18-10 with TiC are compared to uncoated ones in order to determine the cumulative mass loss and the wear.

RESULTS AND DISCUSSION

The microstructure of the coatings is revealing the allocation of the harder particles in the matrics.

Since the resulting composites obtained in experimental conditions are of small thickness ≈ 1,4 mm, the study of the mechanical properties consists of measurement of microhardness [6,7,8]. The present measurement of microhardness is following the Vickers method. Reported are the average values of the measurements.

The study of the micro hardness parameters give an idea of the overall picture of the mechanical properties of the material and of its structural features. The special position of the microhardness among the other mechanical properties is a sequence of the mare physical nature of the test. In fact it is a complex internal characteristic, depending on the basic mechanical properties of the material and is thus fully characterizing the elastic-plastic properties.

With the testing of the TiC samples is obtained a departure of -6% and a lap wear of 0.01 mm thus showing the increase in the wear resistance properties for the MMC sample.

The wear resistivity can be seen in the chart of figure 4.

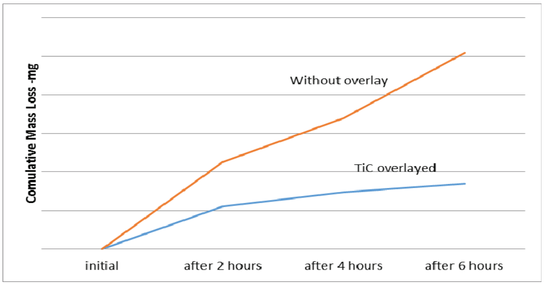


Fig. 4 Slurry abrasion response determination by Miller Number System

The figure shows that the measured values of the microhardness of the zones formed in the metal matrix composite from 0.3 to 0.7 mm, exceeded significantly the values of the hardness of the steel base layer located at a depth of 0.7 to 1.2 mm. Which shows that in this zone has been formed a layer with a metal composite with strength of the reinforcing layer larger than the base material layer. Smoothness of the distribution curve and the absence of the peak values of the hardness shows that the metal composite is completely connected and in thermo-dynamic and kinetic coherence with the primary phase. Roughness values for the tested samples are showing Ra=0.8 μm initial up to Ra=2.25 μm after the wear test.

CONCLUSIONS

Coatings with tailored properties were deposited by laser cladding through different powders introduction in the melting pool.

From the tests performed can be drawn the following conclusions:

• The technological procedure for laser cladding obtainment of metal matrix composite based on X2CrTi12, X5CrNi18-10 and X1NiCrMoCuN20-18-7 steels is proposed;

• Examined were the microhardness and abrasive response of the metallic composite material in order to characterize the obtained stable multiphase system;

• The measured values of the microhardness in the areas of the formed metal matrix composite significantly exceed the hardness of original steel X2CrTi12, X5CrNi18-10 and X1NiCrMoCuN20-18-7 thus allowing the receiving of hardfaced layers without losing the ductile and corrosion resistivity of the metal inside.

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