ABSTRACT

Metal matrix composite materials have wide and various applications in modern industry. Some of them require the deposition of a ceramic coating. This paper reports a new approach to formation of surface metal composites based on silicon carbide using an overlaying technology. The latter is based on the application of an arc which is formed between the metal surface acting as an anode and C-welding rod acting as a cathode. When the arc is started the cathode is heated and releases a stream of electrons of a temperature of ca 4000 K bombarding the anode. Partial melting of the surface layer and formation of a coating of silicon carbide is achieved by adjusting the advance distance between the surface and the electrode as well as the current applied. The metal melt covers the reinforcing phase particles and a solid structure is obtained. The realization of the carbothermal reduction requires the deposition of a coating of a silicon dioxide on the metal surface. Its location and size, as well as the border between carbide layer and the metal surface are determined by microscopic analysis.

Keywords: metal surface, silicon carbide coating, carbide layer.

INTRODUCTION

The creation of new composite materials providing good strength characteristics as well as increased wear and surface corrosion resistance of metals and metal alloys is particularly relevant nowadays.

The most important requirements concerning the modern construction materials refer to a minimum weight, maximum strength and stability, maximum service life and high reliability. These requirements are entirely satisfied by the use of composite materials.

Composite materials with a metal matrix and reinforcing fibers of tungsten, titanium, niobium and others materials [1 - 3] constitute the main part of the composites used. The continuous primary phase or the matrix is metallic. Its role is to accept different external strains and deliver them to the reinforcement phase, which is an interrupted or a dispersed one. But this approach to composite production has several drawbacks determined by the structure non-uniformity and differing anisotropy.

A promising solution of these drawbacks refers to the use of eutectic metal composite materials which are characterized by a structure thermally stable at temperatures close to that of melting. When compared to conventional composites, they have a high strength determined by the strength of the reinforcing phase and perfect unity between the two phases from thermodynamic and kinetic point of view. The studies carried out show that it is a nearly eutectic mixture whose composition orients the crystallization in a specific direction, i.e. the phases form in the direction of crystallization. The one-stage preparation of composites reinforced with a fixed structure in absence of any complex and labor-intensive process steps [4] is the main advantage.
of the eutectic composites. Furthermore the latter have high creep resistance and reveal improved ductility and wear- and corrosion resistance.

A promising approach to meet the requirements pointed above refers to the production of surface metal composites based on cermets. The latter are heterogeneous composites of a metal or an alloy with one or more ceramic phases. Studies of the metal-ceramic system are very important, especially those focused on the adhesion strength at the interface between the two phases.

Cermets preparation through liquid phase sintering provides to fulfill the requirement for maximum strength as the density obtained is close to the theoretical one. Systems based on cermets metal-oxygen free refractory compound (borides, nitrides, carbides, silicides) are practically the product of this method.

The processing of metals of concentrated energy flows results in the formation of structures and phases unusual for classic volumetric heat treatment. Thus large quantities of retained austenite ranging from 82 % to 90 % [5] are obtained in case of processing high-alloyed tool steel by melting the surface.

A new approach to the formation of the metal structure of surface metal composites based on SiC (silicon carbide) is proposed. The electric technology used is based on the effect of an arc formed between the metal surface acting as an anode and a C-electrode performing as the cathode.

**EXPERIMENTAL**

Plates of carbon steel and silicon dioxide (SiO₂) colloidal solution were used for the preparation of the samples. The particle size was varying in the range of 5 nm – 100 nm. Ethanol was the binding component used. The steps of the samples preparation referred to prereliminary heating followed by spraying of ethanol (98 %) onto the surface and immediate introduction to the colloidal solution. The thickness of the layer was 1 mm - 2 mm.

The MMA welding process was used for fusing the obtained layer and the steel. The carbon electrode was with d = 4,0 mm and 305 mm width, whereas the parameters of the overlaying were: I ≈ 140 A, V ≈ 21 V.

The cathode was heated when the arc started to function and released a stream of electrons bombarding the anode with a temperature of ca 4000 K.

The radiation of the arc depended mainly on the temperature of the anode, which emitted ca 85 % of the energy, while the cathode accounted for 10 % of the radiation coming from the gas cloud of the flame and 5 % of the total energy of the radiation.

**RESULTS AND DISCUSSION**

The metal is melted, covering the particles or fibers of the reinforcing phase and connects them through temperature decrease into a solid structure. It is considered that the partial dissolution of the reinforcing phase which proceeds in the metal matrix at the sintering temperature determines the formation of a strong adhesive bond. But the wetting and the interactions at the interface have to be carefully managed. The surface tension is very strongly influenced by impurities, while the use of pure metals is not advised. The impurities’ harmful effects can be greatly decreased by solid phase sintering. The latter is used in the synthesis of metal-oxide based cermets system. It is necessary to find ways of ensuring a strong adhesive bond to the interface. A possible approach refers to the incorporation of an additive as in the case of Mo added to the TiC-Ni system.

In Cr-Al₂O₃ system a film of Cr₂O₃ is formed on the chromium particles surface. It is isomorphic with Cr₂O₃ and rapidly forms a solid solution as a strong adhesive bonding is developed. New methods of synthesis are used recently. These are the molding through blasting and the sol-gel method. The latter is particularly promising as the fibers are impregnated with a colloidal solution and the gel is converted to a ceramic material upon drying and heating. There is no danger of damaging the fibers, their distribution is uniform, and the synthesis is carried out at low temperatures, but the process is accompanied by a very large shrinkage.

The methods described above have a number of shortcomings, which make them ineffective in many cases. The proposed method for silicon carbide overlay is direct. SiC layer obtained is characterized by high hardness (about 9 on the Mohs scale), a high melting point and chemical inertness. The method itself is based on the arc’s high energy field and the carbothermal reduction:

\[ \text{SiO}_2 + 3\text{C} = \text{SiC} + 2\text{C} \]

The microstructure of the surface is shown in Fig. 1, while
SiO₂ coating is illustrated in Fig. 2. A colloidal solution of silicon dioxide is used. The metal surface treated with the latter is connected to the positive side of a current transformer. The C-based welding electrode connected to the negative pole is placed above it. The electric arc developed between the anode (metal surface) and the cathode (C-based welding electrode) destructs partially the electrode and saturates the heated metal surface with carbon and SiO₂. The regulation of the distance between the surface of the welding electrode and the power source provides the conditions for partial melting of the surface layer and silicate carbides formation. The metal melted covers the particles of the reinforcement phase and compresses them into a dense structure at temperature decrease.

Fig. 3 illustrates the microstructure of a metal surface with a carbide coating, while Fig. 4 shows the border between the carbide layer and the metal surface. The carbide crystals create a surface layer which penetrates to the depth of the metal structure (Fig. 5) and has the characteristics of silicate carbide.

The cross sectional view (Fig. 5) provides the determination of the depth to which the carbides adheres. It is usually ca 250 μm but it can be regulated within a narrow range by changing the power and the distance between the electrodes.

The energy required for conducting the process is determined by the relative heat quantity Q for the carbothermal reaction proceeding, for heating the surface layer and the corresponding losses.

The heat required for heating the metal surface is estimated on the ground of:

\[ Q_H = m_m cT, \text{ kJ} \]

where \( c \) is the average specific heat capacity of the metal (kJ kg⁻¹ K⁻¹), while \( m_m \) is the metal mass (kg).

The heat required for the surface layer melting is evaluated using:

\[ Q_{sm} = m_{sm} q, \text{ kJ} \]
Where $q$ is the hidden heat for metal melting (kJ/kg), while msm is the surface layer mass (kg). The latter depends on the depth to which the surface treatment proceeds.

The heat of the carbothermal reaction [6] is:

$$\text{SiO}_2 + 3\text{C} = \text{SiC} + 2\text{CO} \quad -119 \text{ K cal}$$

(Corresponding to 2970 kcal g$^{-1}$ SiC, 528 kJ mol$^{-1}$ SiC)

The total energy defines the current and voltage for the surface treatment applied.

**CONCLUSIONS**

A silicon carbide layer on a steel plate is obtained. An electrical arc is used to carry out the carbothermal reduction in correspondence with SiO$_2 + 3\text{C} = \text{SiC} + 2\text{CO}$. SiO$_2$ is initially applied to the metal surface. Then the sample is immersed in a colloidal solution of silicon dioxide.

The electric arc obtained between the anode and the cathode destructs partially the electrode and saturates the heated SiO$_2$ surface with carbon. Partial melting of the surface layer and formation of a silicone carbide coating is achieved by preliminary regulation of the distances between the surface, the cathode and the current source. The molten metal covers the particles of the reinforced phase and binds them together into a dense structure on temperature decrease.

The depth of the carbide’s adhering is defined. It is usually ca 250 μm but can be regulated in a narrow range by controlling the power and the distance between the electrodes.

**REFERENCES**