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Remelting treatment of the non-conductive oxide coatings by means of the modified GTAW method

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ABSTRACT

The primary objective of the study was to adapt the GTAW (Gas Tungsten Arc Welding) technique for the purposes of the surface remelting processing of non-conductive plasma sprayed coatings. Modification concerned the surface layer of complex oxide compositions based on ZrO_2 and Al_2O_3, which had been applied onto a steel substrate using the plasma spraying technique. In the course of research it was demonstrated that the process of surface remelting of non-conductive oxide coatings may be successfully conducted using welding sources of heat provided that the standard welding station is previously redesigned and additionally equipped. The methodological and apparatus-related work undertaken led to the development and construction of a welding set with a free independent arc, in which the active participation of the oxide coating in the creation of the electric arc and its stabilisation has been eliminated.

The effects of the remelting treatment on the structure of the plasma sprayed coatings have been investigated. The microstructures of both the as-deposited and the remelted coatings were observed by optical microscope and scanning electron microscope (SEM). Observation of the remelted coating structure allowed to distinguish areas with characteristic structural and morphological effects and changes in the structure thereof. On the basis of regularities noted and observations made, a zonal model of the remelted coating structure was put forward and elaborated.

1. Introduction

The use of remelting surface treatment in the process of shaping the structure and properties of plasma sprayed coatings is a dynamically developing aspect of surface engineering, which is proven by the numerous publications and scientific elaborations concerning this subject [1–8]. The main practical goal for this treatment is the improvement of the operational parameters for plasma sprayed coatings by the reduction of porosity, homogenisation of the coating material, and the improvement of the coating adhesion to the base material. The results presented in the literature, as well as previous research conducted by the authors of this elaboration [9,10], indicate that remelting treatment and the accompanying rapid crystallisation of the coating material can be used as a very effective and promising method of coating “rebuilding”, in turn leading to the elimination of the typical characteristics of plasma sprayed coatings. The remelting of the plasma sprayed coating surface is usually realised by means of a laser beam. The decision on the method of remelting does not always come from the properties of the remelted material or the economy of process, but very often, it is from the lack of alternative solutions. The alternative solution for laser techniques seems to be the use of welding heat sources — the use of which is not only justified by economical reasons, but also by the accessibility of equipment, abundance of technology, simplicity of realisation and moderately low requirements set for treated surfaces. The use of a laser beam is, however, connected with the necessity of the appropriate preparation of the surface, since the surface reflectivity issue is a serious technological problem, especially as far as metallic materials are concerned. In case of electron beam techniques, the modification of the surface with the electron flux method requires a vacuum chamber, and this will limit the maximum sizes of the parts subjected to such a treatment. However, taking into consideration that the relationship between the cost of purchase and assembly and the maintenance of the laser, electron flux, and welding equipment is 100:50:5, the use of the GTAW method in the remelting treatment seems to be fully reasonable and justified. The only solution competing with the GTAW method seems to be remelting with plasma arc.

The importance of the Al_2O_3 and ZrO_2 based coating compositions in modern material engineering was one of the primary reasons for the selection of those exact oxides as the study material for this project. Zircon dioxide is a material that, due to its thermo-physical, chemical, and mechanical properties, i.e. low heat conductivity and Young modulus, high corrosion and erosion resistance, heat shock resistance, and high hardness, is especially predestined for thermo-insulation purposes, e.g. for the so-called thermal barrier coatings (TBCs) [11,12]. TBCs, including YSZ-TBCs (yttria stabilised zirconia), are used in power engineering (the parts of both heat and gas turbines, combustion

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chamber lining, turbine blades, etc.), in the automotive industry (the parts of diesel and other internal combustion engines, e.g. cylinder heads, piston rings, cylinder liners), and the aircraft industry (combustors in turbines, parts of rocket jet nozzles). TBCs protect from high-temperature corrosion and erosion. The use of TBC coatings, e.g. in gas turbines and diesel engines is limited by the reactions between the stabilisers present in the coating and sulphur contaminants (Na_2SO_4), sodium (NaCl), and vanadium (V_2O_5) originated from the fuel used. These contaminants, while moving through the porous coating, may cause high-temperature corrosion also in the metallic base [8,13]. Therefore, it is essential to prevent those reactions as efficiently as possible. An alternation of the coating associated with the remelting treatment in conjunction with the controlled porosity reduction provides a possibility to limit those adverse processes and increase the durability of the element coated with TBC.

An interesting material is Al_2O_3. The coating compositions based on aluminium oxide are an important group of coating ceramic materials. The most common use of these materials, as the diversification of the application domain, is first of all the effect of the highest chemical resistance in comparison to all other oxides (particularly to acids and reducing agents), good both thermo- and electro-insulating properties, significant hardness and resistance to abrasion wear, as well as a high melting point (2323 K) [14,15]. The process of the remelting of Al_2O_3 provides the possibility to improve the mechanical properties, hardness, abrasion resistance, and resistance to corrosion. These properties are to a significant degree the resulting effect of the porosity of the layer, the extent of which can be well modelled by remelting treatment.

The main practical goal for the present paper is the approach to adapt a GTAW (Gas Tungsten Arc Welding) method for the remelting treatment of plasma sprayed oxide coatings. The adaptation of GTAW welding method for use in the remelting treatment of plasma sprayed coatings, apart from the measurable cognitive and applicative benefits and the expansion of the available instrumentation, becomes additionally an expression of breaking certain stereotypes, according to which the usefulness of such heat sources is limited to welding purposes only.

2. Experimental materials

The material for the investigations was in the form of oxide compositions based on ZrO_2 and Al_2O_3 deposited on a steel substrate with the use of plasma spraying.

The SEM image of the coating powder is presented in Fig. 1. The chemical composition, grain size and commercial names of powders used are summarised in Table 1. As the base for coating the X5CrNi18-10 steel with nominal dimensions of 70×30×6 mm was used. Prior to plasma spray deposition, the substrates were cleaned and grit-blasted with silicon carbide particles to enhance coating adherence and to remove any surface contaminants. The plasma spraying process was carried out by means of the PN-120 set (ZDAU-IBJ, Poland). The summary of deposition parameters is presented in Table 2. Thickness of the layers obtained varied between 200 and 300 μm. The interlayer in the Al_2O_3–TiO_2 coatings was realised from Ni–Al (80/20) powder. The samples prior to and after the treatment were subject to comparative examination. To examine the surfaces and cross-sections of both sprayed and remelted coatings the optical (Neophot 2) and scanning electron microscope (JEOL JSM 5400) were used. For the SEM tests the analysed samples were coated with a conductive layer of carbon.

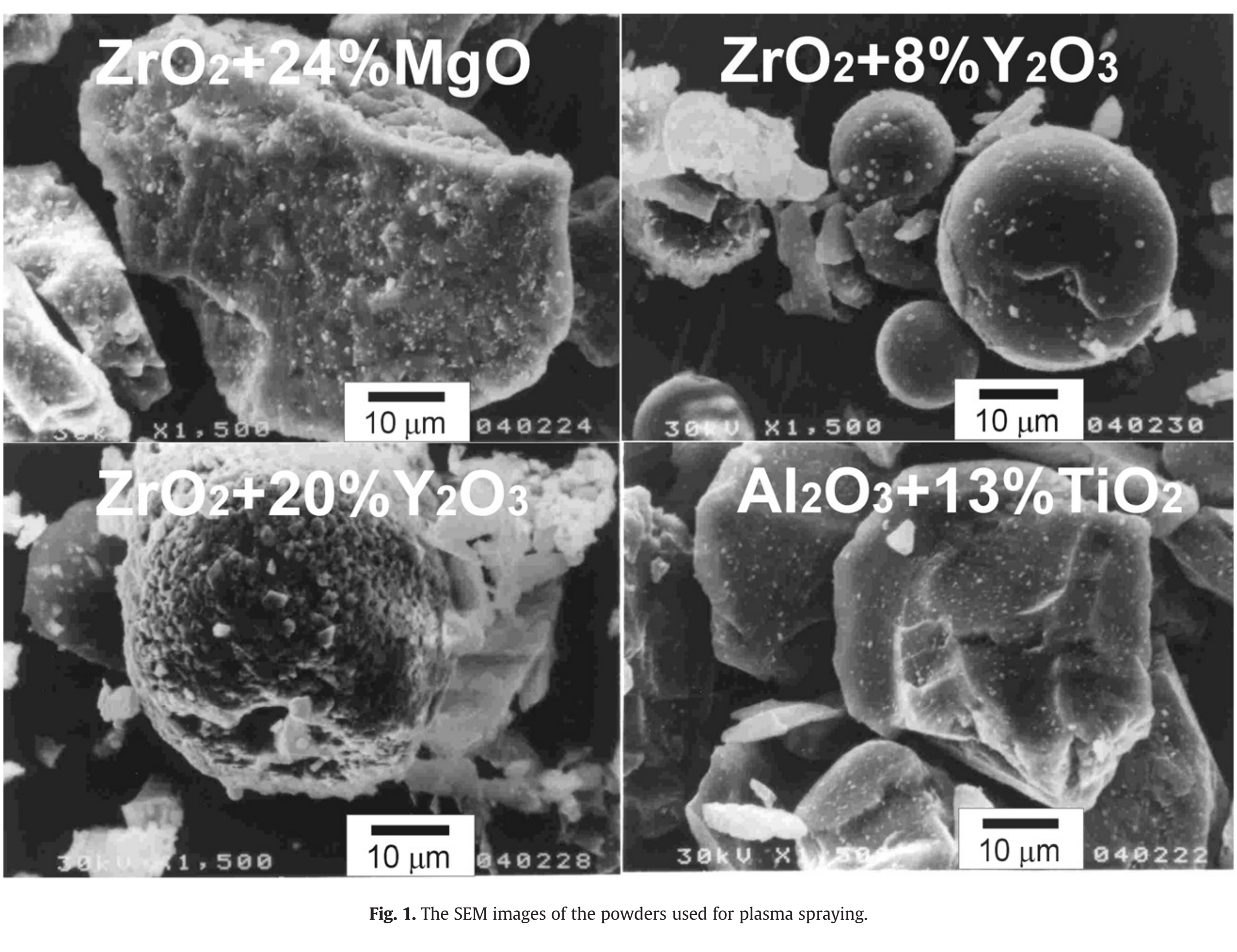

Fig. 1. The SEM images of the powders used for plasma spraying.