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Laser remelting of Al-Fe-TiO_3 composite powder incorporated in a aluminium matrix

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Materials

ABSTRACT

Purpose: This paper describes the process of a laser beam effect on aluminium composite powders with iron titanium oxide.

Design/methodology/approach: The powder was obtained by mechanical agglomeration. The fraction of oxide phases reinforcing the aluminium matrix amounted to 30 wt.%. It was assumed in the material and technological conception that the structure of the powders would change and intermetallic phases as well as aluminium oxide would be formed in aluminium matrix. The structure of the powders and of the connections with the metallic matrix was analyzed by optics and scanning microscopy methods, and X-ray microanalysis.

Findings: The correlation of the structure of powders remelted with the substrate was determined, depending on the laser beam intensity. There were aluminium oxide and respective intermetallic phases from the Al-Fe-Ti system present in the eutectic, inhomogeneous structures.

Research limitations/implications: The interaction of high energetic laser beam with the reactive composite powders is a very complex process. Laser parameters process such as density of laser energy the time of interactions could be optimized to o find the operational laser parameter window for satisfactory remelting of the AlFeTiO_3 composite.

Originality/value: The research results characterize the multiphase ceramic matrix composite structure of connections formed by the interaction of high intensity CO_2 laser beam with the reactive powder.

Keywords: Composites; Surface treatment; Laser; Reaction synthesis; Intermetallic phases

1. Introduction

The current fast development of the laser technology resulting from improvements in high power lasers and a continuous reduction of their purchase and service costs makes lasers become dominating devices which emit a stream of “pure and contact less” energy of very high density [1]. The application of laser techniques for the upper layer modification processes [2,3] enables one to take advantage of the high density of energy of a fast moving laser source in order to obtain very high cooling speeds, in the order of 10^8 K/s [4], of the material subjected to treatment, which in consequence results in the formation of untypical structures of the remelted material, impossible to be obtained by conventional methods [5,6,7]. It was assumed in the material and technological conception presented herein that the high density of the laser beam energy would initiate an exothermic process of melting of reactive composite powders located on an aluminium substrate, thus facilitating the obtaining of an intermetallic phases alloy with aluminium oxide, of a eutectic structure [8,9]. Due to their physicochemical properties, intermetallic phase alloys dispersion-reinforced with ceramic phases belong to the group of advanced materials of a broadening range of applications [10].

The target of the investigations conducted was to determine the technological parameters of laser remelting of $AlFeTiO_3$ composite powders obtained by mechanical alloying of an aluminium powder mixture and a complex $FeTiO_3$ oxide [11], placed on an aluminium matrix. In the investigations, the structure was identified of the eutectic alloy of intermetallic phases with alumina, obtained as a result of laser melting.

2. Experiment

2.1. Composite material

For the production of the $FeTiO_3$ composite powder the particles of 20 μm average granulation making up to 30% vol.% and Al powder of 70 μm average granulation making up to 70 vol.% were subjected to agglomeration in rotary-vibration mill used for mechanical alloying process. The chosen parameters of mechanical alloying had been determined in previous investigations [11]. The obtained agglomerates $AlFeTiO_3$ featured uniform distribution of ceramic particles throughout the whole volume of the aluminium matrix. The powders morphology and the microstructure of the agglomerates $AlFeTiO_3$ - composite powder were examined by means of scanning Electron Microscope, (SEM), Hitachi - (S3400N) using the Energy Dispersive X-ray microanalysis (EDX) system. Images of the $AlFeTiO_3$ surface microstructure and the chemical composition of the elements constitution are presented in Fig.1 and Table 1.

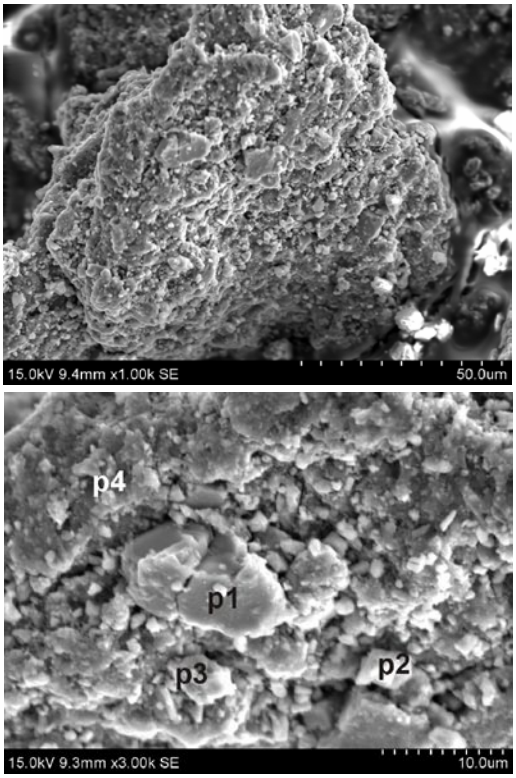

Fig.1. The image of the surface $AlFeTiO_3$ composite powder after mechanical alloying process

Table 1.
Chemical composition of the elements $AlFeTiO_3$ composite powder using EDX microanalysis method

Position at the Fig.1(down)	Al (Wt. %)	Ti (Wt. %)	Fe (Wt. %)
p1	3.72±0.39	42.66±0,27	51.27±0.94
p2	6.75±0.36	39.60±0,21	52.82±1.17
p3	13.79±0.34	36.39±0.24	48.41±0.96
p4	97.53±0.54	0.79±0.15	1.67±0.41
average	60.69±0.32	16.39±0,13	21.99±0.22

2.2. Laser processing

Aluminium plates with 99.6 wt-% purity and 5 mm thickness were used as a metal substrate material. Rectangular 1,2×2 mm notches were made in the middle of the substrate materials. AlFeTiO3 composite powder was pressed in the rectangular notches with 2.5 MPa pressure. The laser processing geometry is illustrated schematically in Fig.2. A continuous 1.8 kW CO_2 laser was used for all experiments in the present work. The laser beam was defocused on the top surface of the workpiece to a spot size of 2 mm. The workpiece movement was realized through a CNC worktable controlled by PC computer. Argon gas at 20 l/min was blown axially to the laser beam axis to protect the focusing lens and to shield the melted area. The traveling speed of specimen was selected from 5 to 10 cm/min.

3. Result and discussion

The electromagnetic radiation emitted by a CO_2 laser is strongly absorbed by the Al-$FeTiO_3$ composite powder. During the first laser beam transition, ca. 80% of the beam energy is absorbed in the surface layer of the preplaced composite powder [12], as shown in Fig. 2. The laser beam energy at this state is not effectively transferred deep into the powder composite, since thermal conductivity of a compact powder is by ca. 10^7 lower than that of the aluminium matrix. The laser beam during its first transition initiates an exothermic reaction in the composite material surface layer. As a result, a synthesis begins in individual grains and, coupled with it, transmission of thermal energy. The composite powder grain begins to melt and a heterogenic mixture is formed, composed of intermetallic phases from Fe-Al and Ti-Al systems, aluminium oxide and the non-reacted aluminium matrix. The energy supplied in successive transitions of the laser beam increased the dynamics of the exothermic chemical reactions of a synthesis of the Al-Fe-Ti intermetallic phase's alloy with aluminium oxide. The final effect is a fully remelted Al-$FeTiO_3$ composite powder in the area of the laser beam action, and the formation of a eutectic alloy structure in its middle part, as shown in Fig. 3 a,b,c. The powder remelting process with a laser beam moving along the treated surface at a constant speed, and with the initiated by the laser beam energy exothermic reactions, is a dynamic process. In the right section (Fig. 3), typical effects of quick crystallization are visible, with columnar crystals oriented so that their growth direction corresponds to the direction of the highest temperatures gradient [13].

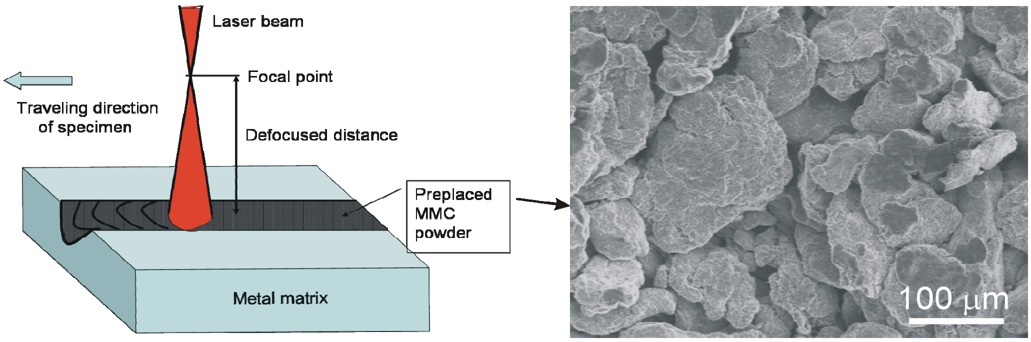

Fig.2. Schematic diagram of the CO_2 laser remelting geometry of the preplaced AlFeTiO3 composite powder

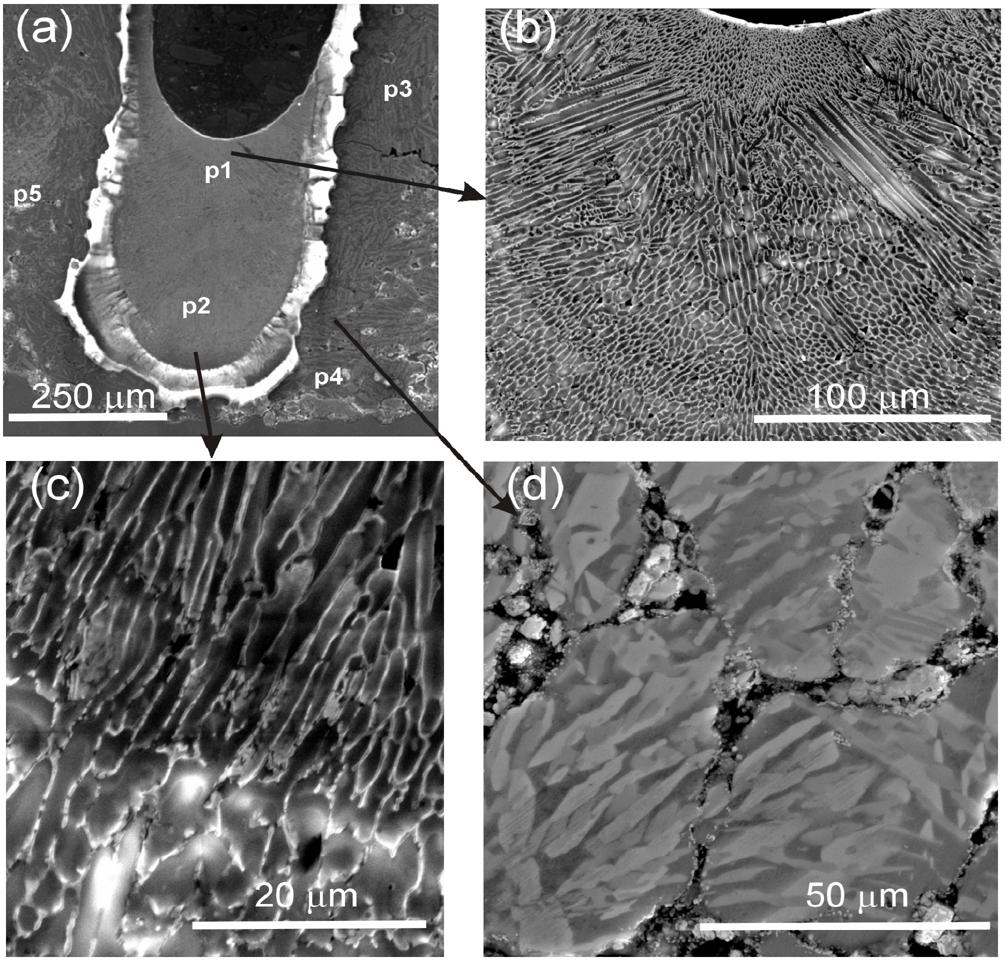

Fig.3. An SEM micrograph of the microstructure of the overall cross-sectional laser alloying $AlFeTiO_3$ composite powder incorporated in a aluminium matrix produced at 10^5 (W/cm^2) laser energy density and 6,5 cm/s laser beam speed

In the fragment of composite material presented in Fig. 3(a), (b), the composite components were completely remelted and blended together. Table 2 shows the chemical composition of selected areas of an analysis of the structure formed. It also shows that in the middle part, Fig. 3(a) p1 and p2, Al_2O_3 dendrites surrounded by Al_3Ti alloy are visible.

As a result of laser melting, the compact aluminium oxide zone migrates before the alloy crystallization front. Around the remelted composite material behind the oxides' zone, loosely joined grains of the composite powder are visible Fig. 3 (d), in which intermetallic phases were formed as a result of the heat coming from the self-propagating high-temperature synthesis

(SHS) [14]. The anticipated reactions that take place between the oxides and aluminium can be described with a general formula:

$$(2y+3m+z)\mathrm{Al} + 3\mathrm{Me}x\mathrm{O}y \rightarrow z\mathrm{Al} + 3\mathrm{Me}x\mathrm{Al}m + y\mathrm{Al_2O_3} \quad (1)$$

In our case, after laser remelting of the Al-$FeTiO_3$ composite powder, intermetallic phases or their alloy and aluminium oxide are formed. Some examples of such reactions are as follows [15]:

$$4\mathrm{Al}+\mathrm{FeTiO_3} \rightarrow \mathrm{AlFeI}+\mathrm{AlTi}+\mathrm{Al_2O_3} \quad (2a)$$
$$8\mathrm{Al}+\mathrm{FeTiO_3} \rightarrow \mathrm{Al_3Fe} + \mathrm{Al_3Ti}+ \mathrm{Al_2O_3} \quad (2b)$$

The best effects of laser remelting of the AlFeTiO3 composite powder were obtained when applying surface energy of 5×10^5 W/cm^2 density and a scanning speed of 6 cm/min, with the laser beam passing three times through the surface subjected to treatment.

Table 2.
Chemical composition of the elements performed on laser remelted $AlFeTiO_3$ composite using EDX microanalysis method

position at the Fig.1(a)	Al (Wt %)	Ti (Wt%)	Fe (Wt%)
p1	81.33±0,39	18.69±0,27	0
p2	82.80±0,36	17.20±0,21	0
p3	75.23±0,32	10.20±0,13	14.57±0,22
p4	88.45±0.38	6.33±0.15	5.22±0.22
p5	76.69±0.32	9.34±0.13	13.97±0.22

4. Conclusions

The obtained results show that the effect of a continuous concentrated CO_2 laser beam action on the $AlFeTiO_3$ composite powder incorporated in an aluminium matrix and subjected to pre-thickening is a multi-phase melting process and in the final phase, quick crystallization completed with the formation of a eutectic Al-Fe-Ti-O alloy. The investigations performed show that an advantageous microstructure of the remelted composite powder is obtained after its repeated remelting with a laser beam of energy, the density of which exceeds 10^5 (W/cm^2). Successive passing of a laser beam, the latter being treated in this case as a superficial source of energy moving at a constant speed, induces a cycle of thermodynamic processes in the composite powder and in the alloy. An analysis of the structure and chemical composition of the eutectic alloy formed as a result of a very quick temperature increase and quick crystallization of the alloy corroborates the assumed material and technological conception of the research.

The results of this stage of the research project allow the supposition that the solution consisting in the application of a laser beam to remelt reactive composite powders with changing their chemical compositions can be applied to produce coatings of a dispersive and eutectic structure as well as to join intermetallic phase based alloys of a predefined phase composition.

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