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Self-lubricating surface layers produced using laser alloying of bearing steel

A. Piasecki, M. Kotkowiak*, M. Kulka

Poznan University of Technology, Institute of Materials Science and Engineering, Pl. M.Sklodowskiej-Curie 5, 60-965 Poznan, Poland

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ABSTRACT

Laser alloying with boron and solid lubricants (CaF_2 or BaF_2) was used in order to produce the self–lubricating layers on 100CrMnSi6–4 bearing steel. The surface of the base material was coated with a paste consisting of alloying material blended with a diluted polyvinyl alcohol solution. Then, this surface was re-melted by the laser beam using TRUMPF TLF 2600 Turbo CO_2 laser. The produced layer consisted of the two zones: the re–melted zone (MZ) and the heat affected zone (HAZ). The re–melted zone was composed of eutectic mixture (iron borides with martensite) and CaF_2 or BaF_2 particles, locating close to the surface. In the HAZ, the martensite, retained austenite, pearlite and sorbite were observed. The layers were free of cracks or gas pores. The microhardness of the re–melted zone was equal to about 800 HV and was lower than that-characteristic of the laser-alloyed layer only with boron. During the wear resistance test, the tribofilm was created on the worn surface. This tribofilm consisted of the calcium fluoride or barium fluoride, which was smeared on the surface. This way, the solid lubricant reduced the mass loss of mating parts and improved their tribological properties.

1. Introduction

The wear of the materials is a very big problem because it causes a large loss of the materials and money as well as many failures of mating parts. Nowadays, a lot of various methods were developed in order to improve the wear resistance of bearing steels. Some of them consisted in a special heat treatment, e.g. deep cryogenic treatment [1,2] or the use of the various quenching media [3]. Diffusion surface treatment such as carburizing [4], nitriding [5,6] or boriding [7,8] as well as CVD, PVD and PACVD methods [9–11] were also often applied for that purpose.

Recently, the self–lubricating materials or coatings were also often applied. In that case, the solid lubricants were added to the entire material volume or they were introduced only into the surface layer of material. Solid lubricants could be divided into three groups [12]. The lubricants which could work from -200 °C to room temperature belonged to the first group. The second group included lubricants working effectively from 200 °C to 500 °C, e.g. soft metals (Ag, Sn, Pb), transition metal dichalcogenides (molybdenum and tungsten disulphides, diselenides, and ditellurides), graphite, and polymers (polytetrafluoroethylene, polyimides). The last group included the high temperature solid lubricants (operating temperature above 500 °C) and it contained oxides, fluorides, and sulfates. Fluorides, such as LiF, CaF_2, BaF_2 or NaF, were known as very interesting solid lubricants because of their high chemical and thermal stability. They could be also applied in machinery parts operating in aggressive environment and under high loads. The best lubricating properties of fluorides were obtained above 500 °C since then their transformation from brittle to a plastic state occurred and it was accompanied by low shear strength [13,14]. The self–lubricating materials were usually produced by sintering [15–23]. Amongst methods of such a treatment it would be possible to mention cold compaction and heating [15,16], cold compaction and hot pressing [17,18], hot pressing only [19–21], microwave and pulse electric sintering [22] or spark-plasma-sintering (SPS) [23]. Self-lubricating coatings were usually produced using the following methods: plasma spraying [24], thermal spraying [25], high velocity oxygen fuel (HVOF) spraying [26], laser cladding [13] and laser alloying [27].

In this study, laser alloying of 100CrMnSi6-4 bearing steel was carried out using the mixture of amorphous boron and CaF_2 or BaF_2 as an alloying material. This way, laser-borided layers including solid lubricants were produced. Boron was introduced to the surface of bearing steel in order to form hard iron borides. Calcium or barium fluorides could improve the wear resistance of the layers due to the tribofilm formation on their surface. Based on the previous study [27], it was expected that the re-melted zone of

* Corresponding author.
E-mail address: mateusz.t.kotkowiak@doctorate.put.poznan.pl (M. Kotkowiak).

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Table 1
Chemical composition of material used [wt%].

Material	C	Cr	Mn	Si	Cu	P	S	Fe
100CrMnSi6-4	1.03	1.52	1.08	0.59	0.11	0.022	0.012	Balance

the layers will consist of the eutectic mixture of iron borides and martensite with an amount of solid lubricants, appearing close to the surface. The melting point and density of fluorides (CaF_2 and BaF_2) were lower in comparison with other phases occurring in laser-alloyed layer (borides and martensite). Such a situation caused that particles of solid lubricants had a tendency to float close to the surface of molten pool. The microstructure, hardness and wear resistance of the produced self-lubricating layers were analyzed and compared to some properties of conventional heat treated 100CrMnSi6-4 bearing steel.

2. Experimental details

2.1. Material

In this paper, the 100CrMnSi6–4 bearing steel was studied. The ring-shaped specimen were used. They were characterized by the dimensions as follows: outer diameter – 20 mm, inner diameter – 12 mm and height – 12 mm. The concentrations of the individual elements in the used material were listed in Table 1.

2.2. Laser alloying

Laser alloying process consisted of two stages. During the first stage, the outer cylindrical surface of the sample was covered with a paste including the alloying material. This paste was prepared using amorphous boron and solid lubricant (CaF_2 or BaF_2) which were blended with polyvinyl alcohol. The thickness of paste coating was approximately 100 µm. The mass ratio of amorphous boron to solid lubricant was equal to 5:1. The powders, used for the paste preparation, were shown in Fig. 1. All of them were characterized by particles of a size which didn't exceed 10 µm. Boron particles (Fig. 1a) had a spheroidal form (Fig. 1a) and their size was in the range of 1–10 µm. BaF_2 particles were characterized by a more irregular shape (Fig. 1b) whereas image of CaF_2 particles (Fig. 1c) clearly revealed their cuboidal shape. The selection of such alloying material (mixture of amorphous boron and solid lubricant) resulted from the previous study [27–29]. Boron had to cause the formation of hard iron borides in the laser-alloyed layer. The obtained microstructure, consisting of eutectic mixture of iron borides and martensite, had to improve the wear resistance of

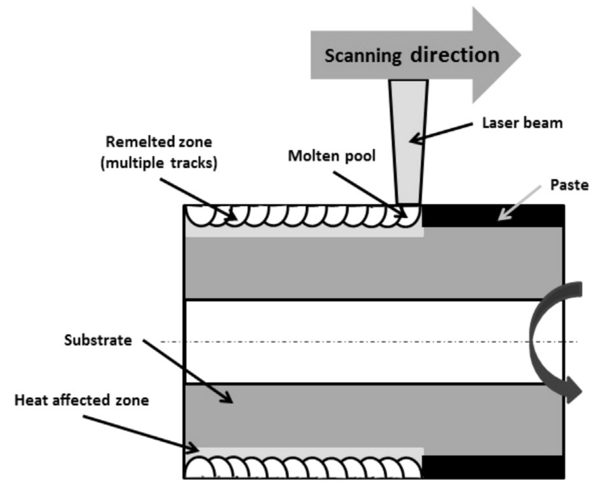

Fig. 2. Scheme of two-step method of laser-alloying.

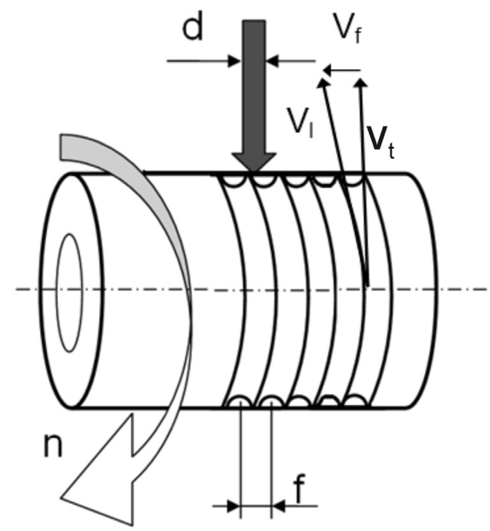

Fig. 3. Multiple tracks producing; d – laser beam diameter (d = 2 mm); v_f - rate of feed; v_l – scanning rate; v_t – tangential speed; n - rotational speed; f – distance from track to track.

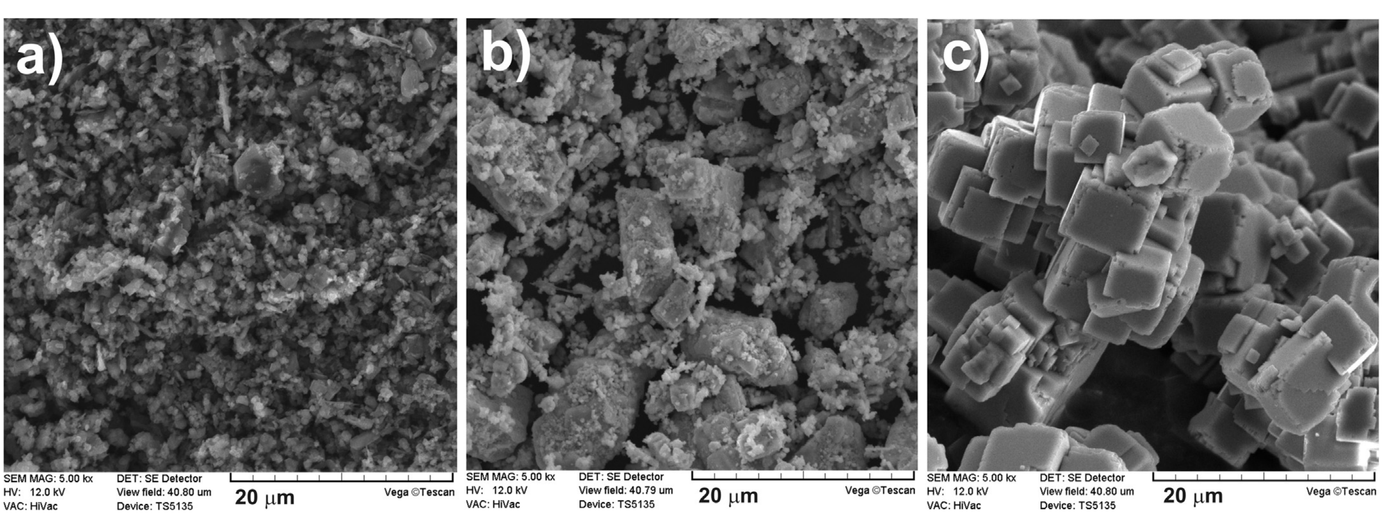

Fig. 1. Components of alloying material: amorphous boron powder (a), BaF_2 powder (b) and CaF_2 powder (c).