The study of surface roughness after thermal-chemical treatment and subsequent grinding

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Abstract. The paper deals with the issues connected to the final machining of diffusion layers formed on the 3Kh2V8F die steel surface by boroaluminizing method. It was established that the surface roughness after boroaluminizing increases by 2.6-5.8 times depending on the time-temperature parameters. Therein the temperature affects the surface roughness ascent more significantly than process duration. After boroaluminizing at 950 °C, Ra has increased from initial 1.5 μm to 4 μm and to 5.44 μm after 2 and 4 hours process duration respectively. As for the 1050°C-process, the values increased to 7.7 μm and 8.76 μm after 2 and 4 hours. Fine grinding as a final machining operation (FMO) of diffusion layers reduces surface roughness by 5.8-45 times depending on the boroaluminizing parameters. However, it was established that Ra values after FMO depend on the initial surface roughness after boroaluminizing. The higher the initial roughness, the higher the roughness after fine grinding. This dependence allows proposing technological heredity effect for the investigated study.

1. Introduction

Hot-work tool steels are commonly used in Die-casting, Forging and Extrusion. They operate under severe conditions and often fail because of deterioration of their working surfaces. For instance, hot forging dies are subjected to severe adhesive and abrasive wear, plastic deformation, induced by high stresses and temperatures [1]. In addition, accumulation of thermal stress over time (thermal fatigue) results in cracking, mainly in the surface layers of dies. It is known, that about 80% of the dies fail by surface crack initiation caused by heat checking during die-casting processes [2]. One of the factors that affect thermal fatigue is surface quality of dies [3]. A tool surface should have low roughness to minimize material adhesion and provide the surface quality of cast metal and workpieces [4, 5].

The current state of mechanical engineering is characterized by wide use of thermal-chemical treatment (TCT) methods – nitriding, cementation, boriding – in the production of diffusion layers and coating with high operational properties [6]. The main disadvantage of the mentioned TCT methods is a limited improvement of operational properties. Another TCT method is two-component diffusion saturation with boron and aluminum - boroaluminizing (BA). It allows to provide a wider set of surface properties of steels and alloys: wear resistance, oxidation resistance at high temperatures, corrosion resistance etc. [7, 8].

As it was mentioned above, the surface roughness has a significant impact on operational properties of tools and dies. It is known that average roughness (Ra) after boriding is low and usually is 0.1-0.8
μm [9-11]. Therefore, it is considered that no subsequent mechanical treatment is needed after boroaluminizing. Nevertheless, recent studies indicate that Ra after boroaluminizing in pastes was 1.5 μm, which is twice as high as in the previous sources and it can be attributed to surface porosity resulting from oxidation. As for the boroaluminized layers, they possess a rough surface (Ra = 7.7 μm). In order to reduce roughness, a final machining operation (or surface finishing) was utilized after boroaluminizing. It allowed obtaining Ra equal to 0.43 μm [12].

The purpose of this paper is to ensure the surface quality of 3Kh2V8F steel after TCT by means of fine grinding. The impact of different time-temperature BA parameters on the surface roughness of the diffusion layers will be studied. The results will allow providing a guaranteed surface quality and establishing technological heredity during diffusion boroaluminizing followed by the surface finishing.

2. Materials and methods

A set of experiments was carried out to reach the goal of this study: TCT at different parameters and fine grinding as final machining operation (FMO). 3Kh2V8F (AISI H21 steel) was utilized in experiments as a material usually used for Die-casting and Forging processes.

The BA was carried out in a muffle furnace without protective atmosphere. Treatment pastes containing powders of boron carbide, aluminium, and sodium fluoride as an activator were used for surface saturation, where the Al/ B2C ratio was 1/5 by weight. Samples of tool steel (dimensions - 20 × 10 × 10 ± ½ mm and Ra = 1.5 μm) were placed in rectangular molds together with the treatment paste. The exposure time were 2 and 4 hours, the processing temperatures were 950 and 1050 °C. After exposure at high temperatures, the samples were cooled outside the furnace in still air at a room temperature.

It is important to provide sufficient diffusion layers thickness for subsequent machining, so upper zones of the layer can be removed as an allowance. From this point of view, a thicker layers high-temperature treatment at 1050 °C is preferable [7].

The FMO was carried out with a vertical milling machine Romi D800. The tool was a borazon grinding head MGS 20.0 × 10.0 for coordinate grinding (manufactured by the MonAliT production company) with a diameter of 20 mm and a grain size of 250 μm. The cutting speed was 250 m/min, the table feed was 0.08 mm/min, and the cutting depth was 0.05 mm.

The microstructure of the samples was studied by the METAM RV-34 metallographic microscope. The surface roughness before and after boroaluminizing, as well as after machining, was measured with a Taylor Hobson Form Talysurf i20 profilometer.

3. Results

The experiments showed that at a boroaluminizing temperature of 950 °C, a predominantly aluminized layer is formed on the surface of alloy steel. The layer thickness is 115 μm after two-hour exposure (Fig. 1a) and 140 μm after four-hour exposure (Fig. 1b). Metallographic analysis revealed that microstructure of the layer on 3Kh2V8F steel is similar to the layer on carbon steel 30 after the same treatment conditions [7]. Three sublayers can be distinguished there. The outer zone of the layer consists of iron aluminide FeAl, a solid solution of aluminum in iron is in the middle and an iron borides chain of small crystals is at the bottom.

Processing at 1050 °C leads to the formation of a layer with heterogeneous structure (Fig. 1c,d) [7, 12]. The layer thickness is much higher than after the treatment at 950 °C. It was measured as 460 μm and 1000 μm after two- and four-hour exposure respectively. Such enormous growth in layer thickness corresponds to the parabolic dependence detected on carbon steel 30 after boroaluminizing at 1100 °C and is related to the austenite composition alignment [7]. The microstructure and phase composition of the layer on 3Kh2V8F steel has been carefully described in [13]. Soft and hard phases are mixed together in each zone (sublayer) of the complex layer. The outer porous zone of the layer contains iron boride FeB and aluminide Fe3Al. It is considered that this zone will be sequentially removed during FMO.
Figure 1. The microstructure of boroaluminized layers on 3Kh2V8F steel: a - 950 °C, 2 hours; b - 950 °C, 4 hours; c - t = 1050 °C, 2 hours; d - 1050 °C, 4 hours.

Based on the optical images in Fig.1 it is clear that the surface roughness after TCT at 950 °C is lower than at 1050 °C. The measurements with a profilometer showed that Ra increased from initial 1.5 μm to 5.44 μm after TCT at 950 °C and to 8.76 μm after TCT at 1050 °C after 4-hour exposure (Figure 3a, b). The roughness increase can be related to surface oxidation during TCT process in pastes. It was discovered that besides mentioned phases - iron boride and aluminide, iron oxide Fe₂O₃ and aluminium nitride AlN form in the upper zone. The presence of latter compounds means that both atmospheric oxygen and nitrogen penetrate through the paste thickness and lead to high porosity of steel surface [13]. As a result of that process, a change in the microrelief occurs, protrusions grow, and other surface micro-irregularities appear.

In order to ensure the surface quality and specified accuracy the final machining of the obtained boroaluminized layers was carried out. Blade machining is not applicable in this case since the layers have high brittleness and shallow depth. According to the recommendations in source [14] fine grinding should be used as an FMO method. Borazon or diamond tools are required for hard materials, coatings and layers such as boroaluminized one. The study of surface topography of steels after TCT and grinding showed that the surface quality can be increased up to 0.18 μm and 1.51 μm after 4-hour BA at 950 °C and 1050 °C respectively (Figure 2 c,d).
Figure 2. Surface roughness profiles of 3Kh2V8F steel after 4-hour TCT\(^1\): a – after BA at 950 °C; b – after BA at 1050 °C; c – after BA at 950 °C and fine grinding; d – after BA at 1050 °C and fine grinding.

\(^1\)Surface roughness profiles after 2-hour BA are given in the ref. [12].

Figure 3. Diagrams of the surface roughness distribution

As can be seen from the diagrams in Figure 4, the surface roughness grows along with the TCT’s temperature and duration. It should be noted that the difference in Ra depending on the temperature is
higher than the dependence on duration and correlates as 3.32-3.7 μm against 1.06-1.44 μm respectively. Thus, the temperature affects the surface roughness more significantly than the process duration.

Fine grinding of diffusion layers reduces their surface roughness by 5.8-45 times depending on the time-temperature parameters of the BA process. However, it is obvious that Ra values after FMO depend on the initial surface roughness after TCT. The higher the initial roughness, the higher the roughness after fine grinding. This dependence allows proposing technological heredity effect for a study. Thus, a further research is needed to determine the FMO regimes.

4. Conclusion
The paper showed the principal possibility of reducing the roughness of boronized layers formed on the surface of 3Kh2V8F die steel by fine grinding using borazon grinding heads. In order to improve the quality and operational properties of diffusion layers, it is necessary to carry out a set of theoretical and experimental work in order to develop methods of assigning TCT and fine grinding modes as FMO process. In this case, it is necessary to take into account technological heredity at each stage of the technological process.

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