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Effects of boronizing process on the surface roughness and dimensions of AISI 1020, AISI 1040 and AISI 2714

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ABSTRACT

In this study, the effects of boronizing treatment on material's dimensional changes and surface roughness were investigated. The parameters chosen were substrate material composition, surface roughness before boronizing treatment, and boronizing time. The AISI 1020, AISI 1040 and AISI 2714 were chosen as substrate materials whereas Ekabor I was selected as boronizing powder. Materials were boronized at 900 °C by using a solid boronizing method for 2 or 4 h. The gradual growth of boride layer on the surface, dimensional changes and their effects on surface roughness were investigated. Variations in topographical surface roughness were determined by SEM. With the boronizing treatment, dimensional increases of the material's were observed. The dimensional increase was one fifth of boride layer thickness for AISI 1020 or AISI 1040, whereas it was one third of boride layer thickness for AISI 2714. Boronizing treatment had also a significant effect on surface roughness of materials. A "threshold roughness" term was defined in our study. This term is a surface roughness value for smooth surfaces, which received boronizing treatment. For the same material and with the same boronizing conditions, the threshold roughness value was achieved after boronizing, when surface roughness of material was below the threshold roughness value, before boronizing was applied. However, when surface roughness of a material was above that threshold roughness value, surface roughness value decreased with boronizing treatment. The thereshold roughness value depended on substrate material composition and boronizing parameters.

1. Introduction

Boronizing is a thermochemical surface hardening process that enriches the material surface by diffusion of boron atoms into the surface at high temperature. Jain and Sundararajan (2002) indicated that the boronizing process could be applied to a wide range of materials including ferrous materials, non-ferrous materials and some super alloys. Boronizing of ferrous materials is generally performed at temperatures ranging from 840 to 1050 °C. The process can be carried out in solid, liquid or gaseous medium. Keddam and Chentouf (2005) suggested that the powder-pack boronizing has the advantages of simplicity and cost-effectiveness in comparison with other boronizing processes. In this technique, the boronizing agent in powder form is placed into a heat resistant box and samples are embedded into this powder under inert gas atmosphere. Meric et al. (2000) concluded that particle size of the powders used in boronizing was a significant processing parameter and in their study the particle size of powder decreased with the increased boride layer thickness.

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Bindal and Üçışık (1999) reported easier diffusion of boron atoms into ferrous alloys and explained this diffusion with the relatively small size and mobile nature of boron atoms. This diffusion mechanism forms FeB and Fe_2B intermetallic, nonoxide, ceramic borides. Depending on the process temperature, the chemical composition of substrate materials, boron potential of medium and boronizing time, single Fe_2B or a double intermetallic phase (FeB, Fe_2B) is obtained by diffusing boron atoms into the surface of metallic materials. Sen et al. (2004) concluded that the interlocking structure of borides with the base metal provides excellent layer adhesion. Metallic borides have relatively high hardness values ranging from 1600 to 2100 HV. The hardness achieved by boronizing increases the resistance to abrasive wear.

In recent years, many studies have been carried out on the boronizing treatment. Most of these studies were based on the use of different materials applied to this process and as a result explain the varying characterization of the obtained surface coating. Allaoui et al. (2006) did studies on XC38 steel, Sahin and Meriç (2002) on different cast irons, Ozbek et al. (2000) on nickel. Some other studies examined the effects of treatment parameters on the boronized surface, as well as the mechanical and the technological properties of these boronized materials. Taktak (2006), Béjar and Moreno (2006), Selçuk et al. (2003) investigated tribological properties of different boronized materials.

A significant amount of work has been done on the acquisition of boriding layers, boronizing mechanism, and phase composition of boride layers. Bartsch and Leonhardt (1999), Filep and Farkas (2005) used plasma boriding in order to obtain boride layer. Novakova et al. (2004) achieved a boride layer on low-carbon steel by using electron-beam boriding method. Keddam (2006) used computer simulations to explain development and transformation of phases of boride layer. On the other hand, Yu et al. (2005) used numerical simulation to explain the same phenomenon. Campos et al. (2007) explained development of boride layer thickness using dimensional analysis.

On the other hand, few researchers have worked on the surface roughness of boriding material. Jain and Sundararajan (2002) found that the initial roughness of the steel sample prior to boronizing ranged from 0.2 to 0.3 μm in R_a, and increased approximately by a factor of 2–3 with boronizing. However, the aforementioned increase in roughness was clearly independent of the pack thickness employed. The increase in roughness of the reasonably smooth surface was due to chemical reaction at the surface resulting in the formation of iron borides. Yu et al. (2005) noted that the surface roughness of the sample increased during the boronizing process while investigating the growth kinetics of boride layer.

The previous studies have not clearly shown the effects of boronizing treatment on dimensional changes and surface roughness of materials. In industrial applications, it is crucial to determine the effects of boronizing treatment on the sample dimensions and surface roughness. Therefore, the goal of this study is to investigate the effects of substrate and boriding conditions on dimensional changes and surface roughness of AISI 1020, AISI 1040 and AISI 2714 steels.

2. Experimental

In this study AISI 1020, AISI 1040 and AISI 2714 steels were chosen as substrate. AISI 1020 and AISI 1040 steels are widely used in different areas of machine constructions. AISI 2714 steels are known as hot work toll steel. The chemical composition of materials used in the experiments was given in Table 1.

For boronizing treatment, the samples were shaped in a cylindrical form with a diameter of 12 mm and a length of 5 mm. Various surface roughnesses were obtained by using different grain sizes (80–1000 mesh) SiC grinding paper in a wet grinding process. For smooth surfaces (A1, B1, C1), polishing was applied to the surface. Boronizing was performed in a solid medium consisting of Ekabor I powders at 900 °C for 2 or 4 h. The samples to be boronized were put in a steel box with Ekabor I powders and then placed in an electrical resistance furnace.

The surface roughness of the samples was measured before and after boronizing using a Mitutoyo Sj-301 profilometer having a diamond tip with 2 μm radius. The sampling length was 3 mm. Roughness measurements were done perpendicular to traces formed by wet grinding process before boronizing treatment. After boronizing treatment, the same measurement procedure was applied to boronized samples. Each measurement was repeated five times and the arithmetic mean value was calculated. The borided specimens were polished before the microstructure analysis to determine boride layer thickness. The thickness of the boride layers was measured by means of a digital thickness-measuring instrument attached to the optical microscope. The dimensions of the samples were measured before and after boronizing. A Mitutoyo 293 series digital micrometer was used to measure the dimensions. The surfaces topography micrographs of the samples were obtained by scanning electron microscopy (SEM).

Table 1 – The chemical compositions of selected substrates

Substrate	Elemental wt.%								
	C	Si	Mn	P	S	Ni	Cr	Mo	N
AISI 1020	0.20	0.189	0.45	0.04	0.050	–	0.16	–	–
AISI 1040	0.39	0.189	0.76	0.035	0.015	–	0.16	–	–
AISI 2714	0.55	0.25	0.70	0.035	0.035	1.76	1.10	0.50	0.16