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Evaluation of borides formed on AISI P20 steel

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Abstract

This study reports on an evaluation of borides formed on AISI P20 steel substrate. Boronizing was performed at 800, 875 and 950 °C for 2, 4, 6 and 8 h by using Ekabor 2 powders. The hardness of borides measured by means of Vickers indenter was about 1500 HVN. The depth of boride layers depending on temperature and process time was ranged from 10 to 180 μm. The presence of borides (e.g., FeB, Fe_2B, MnB, CrB) was confirmed by X-ray diffraction (XRD) analysis technique. SEM cross-sectional examinations revealed that borides formed on AISI P20 has columnar morphology. Depending on the process time, fracture toughness of borides formed on the surface of AISI P20 mold steel ranged from 2.79 to 4.79 MPa $m^{1/2}$. Kinetic studies show a parabolic relationship between layer thickness and process time, and the activation energy is calculated as 200 kJ/mol. Moreover, an attempt was made to investigate the possibility of predicting the iso-thickness of boride layer variation and to establish an empirical relationship between process parameters of boriding and boride layer.

Keywords: Borides; Ekabor; Iso-thickness; Hardness; Fracture toughness; Activation energy; Layer depth

1. Introduction

Boronizing being a thermochemical diffusion process has been applied to a wide range of materials including ferrous materials, non-ferrous materials and some super alloys. Boronizing of a steel surface allows to reduce essentially a rate of corrosion, wear and shaping of fatigue cracks happening in an outcome of its operation. Thermal diffusion treatments of boron compounds to form iron borides typically require process temperatures of 700 and 1000 °C for 1–10 h [1–3]. The process can be carried out in solid, liquid or gaseous medium. The most frequently used method is pack boriding, a process similar to pack carburizing. The diffusion of boron into the surface of selected metal alloys creates a fully dense reaction zone of metal borides. This effectively generates superior surface properties of materials. The diffusion of B into the steel results in formation of iron borides (FeB and Fe_2B) and the thickness of the boride layer is determined by the temperature and time of the treatment. Depending on process temperature, chemical composition of substrate materials, boron potential of medium and boriding time, single-phase Fe_2B or two intermetallic phases (FeB, Fe_2B) are obtained by diffusing boron atoms into the surface of metallic materials. Generally, the formation of a monophase (Fe_2B) with sawtooth morphology is more desirable than a double phase layer with FeB and Fe_2B for industrial applications [4]. The boron rich FeB phase containing approximately 16.23 wt% B is not desirable because FeB (orthorhombic) is more brittle than Fe_2B (tetragonal) phase which is containing 8.8 wt% B. Furthermore, since FeB and Fe_2B phases exhibit substantially different coefficients of thermal expansions, CTE, ($\alpha_{FeB} = 23 \times 10^{-6}/°C$, $\alpha_{Fe_2B} = 7.85 \times 10^{-6}/°C$), crack formation is often observed at the FeB/Fe_2B interface of a double phase layer. These cracks often lead to flaking

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when mechanical load is applied. Through the control of boronizing process parameters, i.e., boronizing powder composition, temperature, time, and laser heat treatment after boriding, Fe_2B phase can be consistently achieved during pack boriding. A single Fe_2B layer produces superior wear resistance and mechanical properties. The main interest has been focused on two peculiar characteristics of the boride coatings which are: (i) high hardness, that is expected to give a high wear resistance, and (ii) columnar morphology, that is required for a good adhesion between coating and substrate. Borides are non-oxide ceramics and are often brittle. Boronized steel outperforms nitrided and carburized steels, because the iron boride formed exhibits substantially higher hardness (HVN = 1600–2000) as compared to carburized or nitrided steels (HVN = 650–900). In particular, boronized steel exhibits excellent resistance to a variety of tribological wear mechanisms. In addition, the resistance of boronized steel to attack by non-oxidizing dilute acids, alkalis and molten metals is also outstanding. In general, the commercial boronizing mixture contains B_4C as donor, KBF_4 as an activator and SiC as diluent which control the boronizing potential of the medium [3,5–13]. At the present study, we attempt to elucidate some mechanical properties of boronized AISI P20 mold steels, e.g., morphology of boride layer, fracture touhness, etc. Specifically, we utilized a Vickers indenter and SEM to determine hardness and microstructures of boronized AISI P20 mold steel.To determine the distribution of alloying elements from surface to interior an energy-dispersive spectroscopy (EDS) was used.

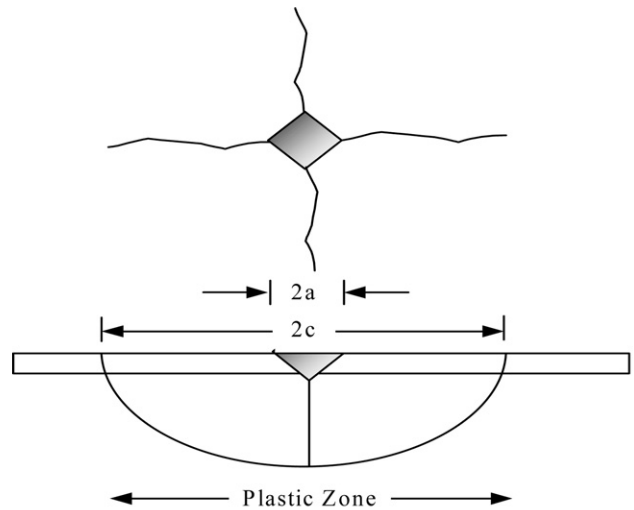
2. Experimental details

2.1. Substrate materials

The substrate used for this study was AISI P20 mold steel essentially containing 0.37 wt% C, 1.16 wt% Cr, 1.12 wt% Ni, 1.42 wt% Mn, 0.17 wt% Mo, 0.29 wt% Si, 0.008 wt% S, 0.011 wt% P and Fe as balance. The test pieces had a disc shape, with nominal dimensions of 15 mm in diameter and 5 mm of high. Before boronizing heat treatment, the samples were ground using 600 grid emery paper to get surface finish. The Vicker hardness of the untreated AISI P20 is 320 HVN and borides formed on the surface of test materials ranged from 1500 to 1650 HVN.

2.2. Boronizing heat treatment

In this study, pack boriding method was used. It was performed under atmospheric pressure at 800, 875 and 950 °C for 2, 4, 6 and 8 h. All samples to be boronized were packed in the powder mix and sealed in a stainless steel container. The container is placed in an electrical furnace and then heated to the process temperature and kept there for a required time and cooled in air.



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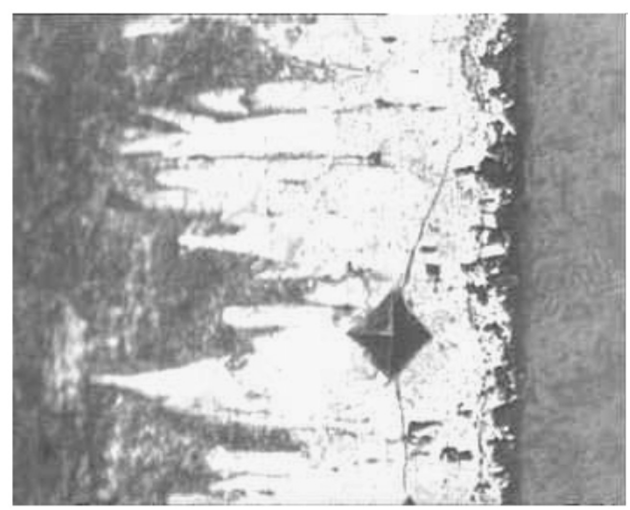

b

Fig. 1. (a) Schematic representation of a Vickers indent in a coated material. (b) Optical micrograph of borided AISI P20 steels including a Vickers indentation in coated layer.

2.3. Characterization of borided samples

A Schimadzu XRD-6000 Model diffractometer with a Cu Kα radiation source of a wavelength of 1.504 Å over a 2θ range from 20° to 100° was employed for XRD analysis of the borides formed on the surface of test materials. The microhardness and fracture toughness of borides were measured by indentation technique using a Vicker's indenter. The equation used for calculating fracture toughness was $K_c = XP/c^{3/2}$ where X is the residual-indentation coefficient [14,15] which depends on hardness-to-modulus ratio (H/E) of the boride layer. The constant X is 0.028 $(E/H)^{1/2}$ where E and H are the Young's modulus and hardness of boride